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## LOCAL SECTIONS

C. C. WILLIAMS, *President of the Society*

The growth in the number and activities of local sections of the Society indicates a healthy vigor in the organization as well as enterprise and spirit on the part of the members. Budding is always an unmistakable sign of life, and the formation of local sections is comparable to budding on a parent stem. These group activities are manifestations of professional vitality, a swelling of ideas locally that can not be compressed into the composite development of the whole organism. Such local opportunities for expression constitute the most favorable means of bringing these ideas to fruition.

Many benefits accrue to the Society from the local sections. In the first place, the local sections, together with the committees of the Society, maintain the group interest in matters pertaining to education and tend to give the Society a year round function. The national convention once a year is a high point of inspiration, but that inspiration needs to be renewed and the ideals refreshed between times if their values are to be conserved. Conversely, the local sections breathe into the parent Society a detailed definiteness in the objectives that eliminates the platitudinous and insures keeping pace with changing conditions.

The pleasantest personal associations that the Society affords are to be found in the meetings of local sections. In the small group intimate acquaintances and conversations are carried over from meeting to meeting, even though the groups may assemble but once a year. The organization takes on the nature of an athletic conference, in a sense, in which certain minor friendly rivalries develop. Inhibitions that arise from larger numbers are absent, and a neighborliness develops that is as enjoyable as the discussions and conversations are stimulating.

With some fifteen sections in operation, assuming that each program averages ten items, some 150 members are given an opportunity in the year to contribute. The general yield from such broad harvesting inevitably multiplies the product of the annual convention many fold. Moreover, the administrative flexibility of these sections should permit anyone to feel that he is not remote from the Society's affairs. Perhaps no more appropriate origin exists for suggestions as to policies and functions of the Society

than in local sections, because the latter implements the desires of members with a usable organization.

Establishing local sections following natural geographical and associative relationships is in all ways commendable. The formation of some strong sections constitutes a notable advance of this year. A palm should go to the section with the largest proportionate representation at the Atlanta Convention.

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## SECTION AND BRANCH MEETINGS

CHAS. G. THATCHER

*Chairman, Committee on Sections and Branches*

The section and branch meetings of our Society offer an ideal opportunity to interest non-members in our activities. A teacher or industrialist who has not joined the Society would find it easy to "meet the crowd" and be at home in these small groups and should find the programs uniformly interesting. Only such technical subjects as are of most general interest should be presented before these meetings, unless it be the custom to divide into special interest groups, as is done in the annual meeting of the parent society. Otherwise papers of general inspiration, and dealing with educational matters will be given and discussed.

It is, therefore, suggested to all who are active in fostering section and branch gatherings, that we make a continual effort to get out to the meetings not only all the membership in that part of the country, but a goodly number of eligible non-members as well. Non-members may be encouraged by having them take an active part in the presentations and discussions, together with other features of the program; thereby adding much to the interest, and eventually, to the membership and success of the Society as a whole.

NORRIS DAM, ON THE CLINCH RIVER, AS IT LOOKS TODAY. The Clinch is shown here flowing through three open sections of the dam. Concreting in these sections will soon be started with a resulting backing up of the river.

## THE ATLANTA MEETING

The 43d annual meeting of the Society will be held at the Georgia School of Technology, Atlanta, June 24–27, 1935. The general theme of the meeting is "Looking Ahead."

The general sessions will be held in the Armory on Monday and Tuesday afternoons, on Wednesday morning and afternoon, and on Thursday morning. The institutional division will meet Thursday afternoon.

Conferences will be held Monday and Tuesday mornings and evenings. There will be conferences on chemical, civil, electrical, industrial and mechanical engineering, coöperative courses, drawing, English, engineering economy, junior colleges, machine design, manufacturing processes, mathematics, mechanics and physics.

The Society will hold a joint meeting with the A. S. M. E. at Norris Dam, Tenn., June 22. This meeting has been arranged by the Knoxville Section, A. S. M. E., in coöperation with the Tennessee Valley Authority.

The annual dinner will be held on the lawn on Wednesday evening. At this time the new officers and Council for 1935–36 will be elected, and the Lamme medal awarded. The speakers at the dinner are Hon. Eugene Talmadge, Governor of the State of Georgia, and Raymond Walters, President, University of Cincinnati.

Georgia School of Technology will use its new dormitories for housing the convention. The rates are $1.50 per person per day for the first day and $1.00 per person after that. Reservations may also be made at hotels. Meals may be obtained in the cafeteria and in dining rooms of the Dining Hall.

There will be an informal get-together Monday evening on the lawn. A very attractive program has been arranged for the ladies attending the convention. Opportunity will be afforded to those who wish to play golf on the course made famous by Bobby Jones.

THE WORK ON NORRIS DAM IS CARRIED ON IN FOUR SHIFTS OF 5½ HOURS, THUS LEAVING TWO HOURS A DAY FOR INSPECTION OF EQUIPMENT. The work is flooded with light at night.

## JOINT MEETING OF A. S. M. E. AND S. P. E. E.
## NORRIS, TENN., JUNE 22, 1935

Arranged by the Knoxville Section A. S. M. E. in Coöperation with the Tennessee Valley Authority

4:00 P.M. Meet at Norris Recreation Hall Auditorium, for the showing of the TVA sound film on the development of the Tennessee Valley Authority.
5:00 P.M. Address by one of the Directors of the TVA.
6:00 P.M. Cafeteria dinner, Norris Cafeteria.
7:00 P.M. Conducted tour of Norris Dam, quarries, and town of Norris, with guide service.

To reach Norris from Cincinnati, take U. S. Route 25–W, through Corbin and Williamsburg, Kentucky, to junction TVA Freeway and U. S. Route 25, one mile north of Coal Creek, Tennessee. Turn left to the town of Norris via Norris Dam, a distance of five miles from Coal Creek. Total distance, Cincinnati to Norris, 265 miles. Norris is 25 miles from Knoxville.

Those who stop over Sunday in Knoxville are advised to take advantage of the opportunity of a trip to the Smoky Mountain Park, which is only an hour's drive from Knoxville. The distance from Knoxville to Atlanta is about 200 miles, with an option of three routes.

## CONFERENCE ON SOIL MECHANICS AND OTHER PHASES OF CIVIL ENGINEERING

Throughout the teaching and engineering professions, unusually keen interest is being evidenced in the forthcoming conference to be held in Atlanta, Ga., on June 24 and 25, at the Annual Meeting of the Civil Engineering Division of the Society for the Promotion of Engineering Education. The program has been arranged to include sessions devoted to "Soil Mechanics," "River Hydraulics," and "Traffic Engineering."

Sessions begin on the morning of June 24 with addresses by Dean C. C. Williams, President, S. P. E. E., Professor Frank Kerekes, Chairman C. E. Division, S. P. E. E., and H. S. Rogers, President, Polytechnic Institute of Brooklyn. Following the opening session the conference will be divided into three sections devoted to the subjects indicated above.

The structural section will be devoted to a discussion of basic principles and physical constants in Soil Mechanics, percolation and hydrostatic pressures, foundation pressures, use of models in teaching and demonstrations, and the development of courses of instruction. The hydraulic-sanitary section will consider such problems as the transportation of sediment, use of models in studying river hydraulics and in teaching elementary hydraulic laboratory work. The transportation-surveying division will be occupied by consideration of the general problem of traffic engineering education.

The list of speakers will include: Willard Chevalier, V. Pres. McGraw-Hill Publishing Co., Roy W. Crum, Director, Highway Research Board, Glennon Gilboy, M. I. T., Arthur Casagrande, Harvard University, W. S. Housel, Michigan University, D. P. Krynine, Yale University, R. R. Philippe, Director, Soils Laboratory, U. S. Engineers, Zanesville, Ohio, D. M. Burmister, Columbia University, F. T. Mavis, Iowa Institute Hydraulic Research, and K. C. Reynolds, M. I. T. Invitations have also been extended to A. C. Ruge, M. I. T., Miller McClintock, Harvard University, L. W. McIntyre, Consulting Engineer, A. E. Everham, Chairman Construction Division, A. S. C. E., F. W. Stubbs, University of Illinois, L. G. Straub, University of Minnesota, Wallace Lansford, University of Illinois, Anson Marston, Iowa State College, and L. F. Rader, Brooklyn Polytechnic Institute.

Attendance at the conference is open to all who are interested. There will be no registration fee. Adequate housing facilities will

be made available at low cost for those in attendance (including their families) by the Georgia School of Technology. The conference is being planned by the Civil Engineering Council, S. P. E. E., consisting of Frank Kerekes, Chairman, T. R. Agg, Gordon M. Fair, L. E. Grinter, K. C. Reynolds, and Fred L. Plummer. Final plans for the conference are under the direct supervision of Prof. Plummer who may be addressed at Case School of Applied Science, Cleveland, Ohio, for further information.

## CONFERENCE ON HEAT TRANSFER *

### PLACE AND SCOPE OF HEAT TRANSFER COURSES IN CHEMICAL ENGINEERING

By O. A. HOUGEN

Associate Professor of Chemical Engineering, University of Wisconsin

What is the reason for the greatly renewed interest and emphasis placed upon the study of heat transmission during the last fifteen years? It has been one hundred and twelve years since the mathematical theory of heat conduction was developed fully by Fourier, followed closely by the classical series expansions of Poisson, Duhamel and Lamé. For a period of one hundred years the underlying theory of heat conduction through solids has been well understood and developed by mathematicians but has received relatively little attention or application by the engineer except for simple problems of steady heat flow. The mechanism of heat transfer into fluid streams was treated mathematically fifty years ago by Boussinesq, Reynolds, and L. Lorenz. The resulting differential equations for heat transfer into moving streams have been so formidable and have offered so many seemingly insurmountable difficulties as to discourage rigorous mathematical solution. Despite the difficulties involved men like Stanton in England and Nusselt in Germany have pushed forward the theoretical and experimental development in the early part of the present century even up to the present time. Probably the principal reason for the recently increased interest and activity in heat transmission has been the presentation of the complex formulas of radiation and of unsteady flow of heat by conduction into readily useable and understandable graphs and charts freed from the forbidding dress of the original involved series equations. The graphs by Gurney and Lurie dealing with heat flow and temperature changes in cooling solids, the equally laborious compilations by Schacht and by Hottel for the intricate problems of radiation translated into simple and useful tables have done much to attract the engineer to the solution of complex problems in heat transfer by simplified methods easily understood. It also appears that the great complexity of heat transfer into moving fluids has expanded from a hopeless jumble of empirical equations and widely scattered data into homogeneous equations retaining the controlling variables ar-

* Held at Cornell meeting, S. P. E. E., June 19, 20, 1934.

ranged in dimensionless groups applicable to the infinite variety of materials through which heat is passed. Much credit must be given to Professor William H. McAdams and his associates for their patience and comprehension in the sifting of experimental data and empirical equations and condensing all to a rational system of presentation which now serves as the basis of further development and is a directing influence for future experimental effort. Summarizing of data into dimensionless equations has led the engineer from an intricate maze of isolated experiments and equations into an orderly path for future progress.

Because of the unlimited variety of materials which the chemical engineer is engaged in heating or cooling it has been necessary for him to take a particular interest in the underlying theories of heat transmission as well as in their applications. As long as the engineer dealt only with a few common fluids such as air and water the problem of heat transmission could be satisfactorily met with a few empirical equations. But obviously when called upon to design the exchangers for heating or cooling the endless variety of petroleum oils, tars, gases, solutions of all descriptions, molasses, viscose, sulfite liquor, or hydrogen gas, the futility of establishing empirical rules at once became obvious, and it became necessary to relate heat transmission coefficients in terms of a few physical properties of the substance arranged in dimensionless groups rather than to establish unique data for each substance.

Two courses in heat transmission should be included in the chemical engineering curriculum, a short elementary course required of all chemical engineers and an advanced course elective by seniors and required of graduate students.

### *Elementary Course*

Because of restricted time in the crowded undergraduate curriculum it usually becomes necessary to limit the elementary courses in heat transmission to from twelve to sixteen lecture-recitation hours. Within this brief period it is necessary to limit the theory to heat flow by conduction in the steady state, to radiation, and to the film concept for the transfer of heat into fluids. The logarithmic mean temperature difference in a heat interchanger should be developed and its limitations thoroughly understood. A few reliable equations for heat transmission coefficients of fluid films in both streamline and turbulent flow should be presented with but little theoretical development. Simple problems should be included in the flow of heat by conduction through furnace walls and cylinders, in the use of the Gurney-Lurie charts for unsteady flow and in the use of Hottel's tables for a few simple problems in

radiation. Problems should be included for calculating the most economical thickness of insulation, and the optimum velocity of blowing air in the design of a heat interchanger for heating fluids. The elementary treatment of heat transmission should be given preferably in the junior year and may be included in the basic course on unit operations.

### *Advanced Course*

An advanced engineering course in heat transmission open by election to senior students and required of all graduate students in chemical engineering should properly be given in any engineering college offering graduate work. The writer sees no special reason why a single advanced course in heat transmission for all branches of engineering is not sufficient. It is to be expected that certain applications of heat transmission will appear in specialized courses such as heating and ventilating, refrigeration, and dynamo design but the general theory can well be given in a single course for all engineers.

An advanced engineering course cannot be adequately presented in less than fifty lecture-recitation hours. The prerequisites of such a course should be senior or graduate standing and preferably an elementary course in differential equations. For a thorough treatment of the theories of heat conduction and radiation advanced mathematical preparation of courses dealing with partial differential equations and with spherical harmonics is essential but such treatment had better be left to advanced courses in physics or mathematics rather than in engineering. The advanced engineering course should include a comprehensive theoretical treatment of all the important phases of heat transmission. For the unsteady flow of heat by conduction it is important to derive the general differential equation and to develop its complete solution for a single case such as for the parallel flow of heat through a slab under definite boundary conditions. For more complicated cases involving different shapes and surface resistances it is sufficient to present the final solutions. The student should be able to prove that such solutions are correct and satisfy the boundary conditions even though he may be unable to make the initial integrations. Professor A. B. Newman has found this procedure to be satisfactory. It is beyond the scope of a three credit course to require the development of Bessel and Fourier series for complex cases but the construction of charts and tables based upon these series should be well understood. In radiation, the concepts of a black body, spectral emission, the distribution laws, Kirchoff's and the Stefan-Boltzman laws should be briefly presented. A single

example of the mathematical development of the average length of radiant beam should be studied, as well as a single example of the derivation of the emissivity and angle factors for radiation interchange between two surfaces of limited area. Further problems involving radiation should then be solved by the use of tables and curves without demanding their mathematical proof.

The study of heat flow into fluid films had best be preceded by a brief review of fluid flow and dimensional analysis. In presenting the subject of convection there is need for much theoretical discussion. The development of the Prandtl analogy between friction and heat flow, the theoretical equations for heat flow through films in natural convection, and the general equations for heat transmission into streamline and turbulent fluids both inside and outside of tubes should be presented. The derivation of the Nusselt equation for the thickness, temperature gradient and transmission coefficients of condensate layers should be required as well as for the heat removed by condensate layers flowing down pipes. In discussing the condensation of vapors from non-condensable gases it is important to present the theory of vapor diffusion and to develop the equations for mass transmission coefficients of condensing vapors in such mixtures.

In an advanced course the derivation of the logarithmic mean temperature difference in a heat interchanger should be given as well as the mean temperature difference for complex cases where heat capacities, transmission coefficients or mass velocities vary widely and in the special cases where flow of fluids is neither parallel nor countercurrent. Among the problems of economic design of heat interchangers should be included calculations of the optimum terminal temperatures of a heat interchanger as well as the usual problems of calculating optimum thickness of insulation and velocity of fluid flow.

It is particularly instructive in studying condensing vapors to include problems involving the condensation of a fixed weight of a given vapor under a variety of conditions, such as of pure vapors on vertical and on horizontal tubes and concluding with the very complex problem of condensing the same vapors from mixtures with non-condensable gases where diffusion coefficients as well as heat transmission coefficients must be considered. In this latter case calculations become very complicated because heat capacities, transmission coefficients, and gas velocities vary enormously over the condenser surface, and part of the heat of condensation is carried by the mechanical flow of the condensate down the tubes.

It is particularly important in presenting complex problems in heat transmission involving several resistances in series to instruct the student in the method of tabulating calculations in order

that a wide range of variables and many details may be treated orderly with economy of time. Alignment charts may be used where many routine calculations are involved and the method of constructing such charts should be described.

Some attention should be given to the discussion of the measurements of surface temperatures and of the average temperatures of moving streams and surfaces as well as to the experimental procedure in measuring properly heat transmission coefficients.

Since the recent publication of McAdam's "Heat Transmission" and the English translation of Alfred Schacht's "Industrial Heat Transfer" by Hans Goldschmidt and Everett Partridge, the engineer looks forward with renewed hope to an orderly and systematic development of data covering the entire category of intricate problems in heat transmission.

## METHODS OF TEACHING HEAT TRANSFER

By WILLIAM H. McADAMS

Professor of Chemical Engineering, Massachusetts Institute of Technology

The following outline touches upon some of the points to be emphasized in a classroom course in heat transfer. The nature and number of the illustrative problems assigned, the relative emphasis upon sources of data, derivations of equations, and detailed methods of correlations, and the division of time between lectures and recitations, will depend upon the nature, purpose, and length of the course. However, in all cases, conduction, convection, and radiation should be clearly defined, and general rate equations presented, even in a course dealing mainly with one type of heat transfer. In preparing the following rough outline, it is assumed that the course is of a general type, rather than limited mainly to a study of some one kind of heat transfer.

### Outline

1. *Statement of Purpose and Scope of Course:*

A study of the fundamental principles underlying each of the three types of heat transfer, together with applications to engineering problems.

2. *Introductory Definitions and Descriptions of Conduction, Convection and Radiation:*

This qualitative material should be accompanied by a presentation of the corresponding rate equations and definition of each

term involved. Although most engineering problems involve more than one mode of heat transfer, the three kinds will first be considered separately.

3. *Conduction:*

(*a*) Discussion of thermal conductivity for both homogeneous and non-homogeneous materials, including effect of various factors. Methods of measurement of thermal conductivity of solids, liquids, and gases should be covered, at least in outline. Discuss conversion of units.

(*b*) Definition of steady and unsteady states.

(*c*) Steady state conduction. Integration of Fourier equation ($dQ/d\Theta = -kA\ dt/dL$) for various shapes. Algebraic derivation of equation for series flow, with and without boundary resistance terms, $1/hA$. Application to optimum thickness of insulation should be postponed until radiation and convection are treated.

(*d*) Unsteady state conduction in solids. Derive second order differential equation from Fourier equation and heat balance; integrate for one simple case, such as the slab, and show that this checks the values read from the usual charts. Present and use charts showing plots of dimensionless ratios appearing in integrated equations for various shapes, referring to various standard works where the methods of integration are given in detail. Show how problems in step-up heating and in non-isotropic heating can be handled by combining solutions available for the usual cases in chart form. Refer to Nessi and Nisolle, "Methodes Graphique pour la Regime Discontinue," Dunod, Paris.

4. *Convection, General:*

(*a*) Discussion of mechanism of fluid flow, both isothermal and non-isothermal.

(*b*) Definition of local individual and overall coefficients, and mean fluid temperature. Derive the relation for steady flow of heat through convection and conduction resistances in series.

(*c*) Discussion of dimensional analysis and dimensionless groups of variables.

(*d*) Derivation of equations for mean temperature difference, stressing limitations involved.

(*e*) Effect of deposits of scale, etc.

(*f*) Discussion of experimental technique and precision of data.

5. *Forced Convection:*

Stress the differences between streamline and turbulent motion for fluid flow parallel to the axis of the tubes. Discuss analogies

between heat transfer and friction. Use dimensional analysis to correlate data, employing consistent units. Discuss conversion of units. Simplify general equations for special cases. Illustrate the use of alignment charts in design work. Derive equations for optimum velocity and optimum tube dimensions, emphasizing their limitations. For streamline flow in tubes, outline the derivations of the Graetz theoretical equation based on conduction in a moving fluid, noting limitations.

For flow of fluid at right angles to tube banks and through baffled heat exchangers, the mechanism of fluid motion is more complicated than inside tubes, but application of dimensional analysis leads to fairly satisfactory correlation of rather inadequate data.

6. *Free Convection:*

The mechanism of fluid flow should be developed to lay the basis for the use of dimensionless groups involving free convection factors to correlate the data for various shapes. Again, charts and simplified equations are of utility.

7. *Condensation:*

The importance of the effect of surface conditions should be stressed. For example, the difference in mechanism, and in coefficients of heat transfer, with film-forming and dropwise condensation should be developed. The Nusselt equations, for streamline flow of condensate in film-type condensation, should be derived, at least in outline, applying fluid dynamics and the conduction equation, for both horizontal and vertical tubes; and limitations emphasized. The effects of superheat should be treated. The Stefan-Maxwell diffusion equation should be utilized in the study of condensation of a vapor mixed with non-condensable gas. Available applications include problems in humidification, dehumidification, and water cooling.

8. *Boiling Liquids:*

The factors to be discussed should include effect of condition and wettability of heating surfaces, arrangement and type of apparatus, temperature difference and temperature level, nature of liquid, velocity of circulation of liquid, possibility of overheating near the heating surfaces, rate of depositions of scale or deposits, and optimum cleaning cycle.

9. *Radiation:*

The basic laws should be presented together with definitions of the various terms involved. Emissivity factors or black-body coefficients should be discussed. In a general course, a typical deriva-

tion should be included to illustrate the method of applying the basic laws to obtain the integrated relation for a special case. The results for a number of common special cases should be presented in the form of tables or charts of angle factors and emissivity factors. Gas radiation should be treated.

10. *Arrangement and Types of Problems:*

During the study of the basic principles of each of the three modes of heat transfer, it is essential to assign numerical problems, later to be collected, discussed, and solved in detail in recitation or conference. These should be of two types (a) simplified problems dealing with the subject matter under immediate consideration, and (b) comprehensive problems involving the several types of heat transfer occurring simultaneously. It is advisable to give unnecessary data in some cases, and insufficient date in others. This serves to develop judgment and to acquaint the student with the sources of data.

11. *Lecture Experiments:*

In the senior course in Chemical Engineering at the Massachusetts Institute of Technology, Prof. C. S. Robinson employs a series of lecture experiments on unit operations, and several experiments on heat transfer are included. During the first part of the hour the students predict the performance of the apparatus, then the experiment is made and the actual results are compared to those predicted. Good results are obtained with simple and inexpensive apparatus. Some of these experiments are described in detail in a recent paper by C. R. Johnson.*

## THERMAL RADIATION—SUBJECT MATTER AND LABORATORY TECHNIQUE

By H. C. HOTTEL

Associate Professor of Fuel Engineering, Department of Chemical Engineering, Massachusetts Institute of Technology

In the not very distant past the extent of instruction in radiant heat transmission available to engineering students included a statement of the Stefan-Boltzmann law of emission of radiation from a surface, followed by a brief consideration of how to apply it to two special cases of heat interchange, parallel planes and a small body enclosed by a much larger one. Although numerous

* "Chemical Engineering Laboratory Experiments," presented at the May, 1934, meeting of the American Institute of Chemical Engineers, F. J. LeMaistre, Secretary, Bellevue Court Bldg., Philadelphia, Pa.

fairly recent books have increased the availability of material suitable for class presentation, they have in general the common faults of lack of comprehensiveness or excessive simplification to the point of being misleading. In this paper I propose to present, in brief outline, material suitable for a course of instruction in radiation of perhaps thirty class periods, realizing of course that if the material is to be included as part of a comprehensive course covering the whole field of heat transmission appreciable condensation is necessary; that if it is to be a part of a course in furnace design, expansion may be desirable.

I. Introduction.

Suitable material for introducing the course is found in a few college physics textbooks and should include

*A.* The Nature of Radiation in general and, more particularly, the nature of thermal radiation.

*B.* The Concept of a Perfect Radiator or Black Body, Kirchoff's law being presented in connection with that concept and not falsely labeled as a useful guide to the actual calculation of heat interchange.

*C.* The Relation between Perfect or Black Body Radiation and Temperature. This should include, if time permits, the thermo-dynamic derivation of the 4th power law, or better, the assignment of its derivation with suitable hints as to procedure.

*D.* The Distribution, in the Spectrum, of Black Body Radiation. If time permits, a derivation of the Planck equation, to indicate the origin of the quantum theory.

*E.* The Exponential Law of Absorption of Monochromatic Radiation in Diathermanous Media.

All this introductory material is excellently treated in Professor Richtmyer's book "Introduction to Modern Physics," based on lectures given at Cornell. It can be presented, without problem assignments, in two to five class periods.

With the foundation laid we are ready to discuss the problem of radiant heat interchange between surfaces, and at least two choices of method of presentation are possible. The general problem of interchange in a system of non-black surfaces might be presented and analyzed, and the interlocked problems of geometrical angle factors, successive selective reflection, and reradiation treated in relation to one another. Experience in teaching material of this sort has convinced me, however, that these concepts are so confusing to the average student, who has probably forgotten much of what he ever knew about solid analytic geometry, as to warrant separate

and successive treatment if possible. Such treatment is possible if we consider first the case of heat interchange among surfaces in a system all parts of which are perfect radiators or black bodies. The necessity for simplifying assumptions will thereby be postponed while the student is familiarizing himself with the nature of the problems of angle factors and reradiation, and the solutions obtained to problems assigned will be exact, a feature desirable in problems assigned early in a course. The second section of the course will then be entitled

II. Radiant Heat Interchange in a System of Black Surfaces, to include

*A*. Fundamental Principles, including

(1) The differential form of the equation expressing emission from a surface, $dq = i.d\omega.\cos\phi$; and an indication of its identity to the square-of-the-distance law familiar to the student from his freshman experiments in photometry.

(2) The integration of the differential equation to give the interchange between two finite surfaces, $A_1$ and $A_2$ and the expression of the result in the form of a factor, $F_{1\to 2}$, the fraction of the radiation leaving $A_1$ in all directions which is intercepted by $A_2$. Not more than one simple case should be assigned for integration to indicate the method; the values of $F$ for various cases should be made available to the class in graphical form, for subsequent solution of assigned problems.

(3) The reciprocal character of the relation giving radiation from either of two surfaces to the other. The relation $A_1 F_{1\to 2} = A_2 F_{2\to 1}$, proved both geometrically and by the use of Prevost's old theory of exchange. This useful and obvious relationship is hard to drive home without the assignment of several problems involving it as a short cut.

*B*. Applications to Multi-Surface Systems.

(1) Several surfaces, each at a uniform temperature

(*a*) All temperatures specified.

(*b*) One surface as a source, one as a sink, with both temperatures specified; other surfaces in thermal equilibrium, with temperatures not given.

(2) Several surfaces, including a source at uniform temperature, a sink at another uniform temperature, and other surfaces in equilibrium, with continuous variation of temperature along their surface. (Example—loss of radiation through an opening in a thick wall of a furnace.)

The student should now be thoroughly familiar with the geometrical problems involved in the evaluation of heat interchange, and with the method of allowing for reradiation, and is ready to consider

III. The Effect of the Non-Black Character of Surfaces on Problems of Interchange of Radiation Between Solids. This section may well be introduced by emphasizing the necessity, from here on, for making simplifying assumptions. At this point in the course the student bids goodbye to the type of problem which is clear-cut and capable of exact solution, and begins to acquire the viewpoint of an engineer.

*A.* The Radiating Characteristics of Actual Surfaces, compared to those of a black body or perfect radiator at the same temperature. This should include a discussion of the various kinds of emissivity, total, normal, monochromatic, etc.; the non-gray character of surfaces; the effect of roughness, degree of oxidation, metallic or non-metallic character, etc., on emissivity; emphasis of the fact that, fortunately, most surfaces of industrial importance have fairly high emissivities, justifying subsequent approximate methods of treatment. Kirchoff's law should be discussed again at this point, with emphasis on its restriction to systems in which no heat interchange occurs. Ritchie's experiment may be described, not as an experimental proof of Kirchoff's law but as a proof of the approximate validity of the assumption that emissivity and absorptivity do not differ greatly so long as there is not much difference in the temperature of the radiations with which they are associated. The generalizations should be followed by consideration of interchange in actual systems similar to those discussed under II above, with the complications due to reflection being superimposed gradually. The simplest case is

*B.* A System in which only One Surface is not Black. This case is relatively easy for the student to consider because of the restrictions to a single reflection.

*C.* Two Surfaces in a System are not Black. This problem introduces the concept of infinite series arising due to successive reflection, a solution being obtainable only with the introduction of several simplifying assumptions.

*D.* All Surfaces Involved are Non-Black. An approximate solution is possible if all reflections beyond the first are neglected.

The next step in complicating the problem of radiant heat interchange is to include the presence of a partially diathermanous medium separating the surfaces. This brings us to a consideration of

IV. Non-luminous Gas Radiation

*A.* Principles.

(1) The general character of gas radiation.

(2) The factors determining its magnitude.

(3) The concept of "mean length of radiating beam" through a gas to its bounding surface.

(4) The allowance for variation in temperature of the gas as it passes through an interchanger.

*B.* Numerical Problems Involving a Gas at One Temperature and a Single Surface at Another. (Example—a gas in a circular duct.)

*C.* A System Including a Gas and Two Surfaces at Different Temperatures, the gas a source or sink, one surface a sink or source, the second surface an intermediate receiver and reradiator, in thermal equilibrium. Here the problem of gas absorption arises. In the older treatment of this type of problem, gas absorption was assumed dependent on the temperature only of the source of radiation; the treatment was known to be a crude approximation. A more nearly exact but also more complex treatment is now possible, with new data available on emission and absorption of carbon dioxide and water vapor. (Lantern slides.)

If the time available for instruction in radiant heat transmission is less than assumed at the beginning of this presentation, here is a convenient place to stop. If, however, effective application of the principles is to be made to industrial problems of high temperature heat transmission, further sections are necessary.

V. Radiation from Clouds of Particles. The evaluation of heat transmission from pulverized coal flames, and from flames made luminous by the presence of products of cracking of hydrocarbons.

The treatment of problems of this type is of necessity less satisfactory than those heretofore considered because of the incompleteness of our knowledge. However, a certain amount of useful material can be presented, supplemented by data on the performance of typical furnaces.

VI. The Simultaneous Operation of All the Mechanisms of heat transmission so far considered in the combustion chamber of a furnace. Complete problems in furnace design may be assigned, nearly always requiring a number of simplifying assumptions to permit a solution to be obtained. The analytical treatment of problems may be supplemented by the empirical method in which, without considering individually the various mechanisms of heat transmission involved, one tries to correlate data on furnace performance in terms of a relatively small number of variables. This approach to the problem is the diametric opposite of that used in the course up to this point. The relative merits of the two methods of attack should be emphasized, and the fact pointed out that when we have made more progress in the analytical method the two methods should overlap.

### *Laboratory Technique*

The limitation of time prevents more than a few generalizations concerning laboratory technique. The engineering student is in general not prepared to attack a research problem in radiant heat transmission as part of an undergraduate or Master's thesis unless the radiometer equipment is already built and, within limits, foolproof. No radiometer has ever been built which was free from effects of stray radiation; these effects are especially troublesome if the research problem involves the measurement of radiation or absorption of a gas confined by hot walls which are theoretically outside the geometrical limits of "vision" of the radiometer receiving surface. Consequently the supervisor must insist on repeated proof that the galvanometer readings recorded and reported as radiation are due in fact to the radiating source to which they are attributed, that proper allowance is being made for stray radiation. A system composed of a thermopile-galvanometer combination of high sensitivity is generally characterized by a certain amount of instability of calibration. Consequently the system

should be calibrated frequently (daily or oftener for good work) by the use of one or more black-body furnaces at various temperatures. The assumption of linear variation of galvanometer reading with intensity of incident radiation should never be made without experimental verification. The possibility of selective reflection of the thermopile surface or of any mirrors used should be investigated by exposure to radiation from standard black bodies at widely different temperatures. If the range of temperatures being investigated is great there must of course be an interconnection of the temperature scales of the thermocouples and an optical pyrometer. If radiation from a surface is being measured, extreme care must be taken in attaching thermocouples to obtain the true surface temperature. A desirable check on the quality of the experimenter's technique is the determination of the radiation from a surface of known radiating characteristics under conditions similar to those prevailing during the study of the unknown surfaces.

Only by the exercise of eternal vigilance in preventing stray effects from entering is one justified in assuming that the readings of a sensitive radiometer system are in reality due to radiation received rather than to some such effect (to take an example from a student research with which I had contact) as the preferential heating of the receiving surface of the thermopile due to compression of the air in the thermopile chamber when the shutter was closed.

## DIMENSIONAL ANALYSIS

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Bridgman (1) states: "The purpose of dimensional analysis is to give certain information about the relations which hold between the measurable quantities associated with various phenomena. The advantage of the method is that it is rapid; it enables us to dispense with making a complete analysis of the situation such as would be involved in writing down the equations of motion of a mechanical system, for example, but on the other hand it does not give as complete information as might be obtained by carrying through a detailed analysis."

"The method depends on a property of all fundamental equations as ordinarily written, namely, that the form of such equations is independent of the size of the various units. For example, the fundamental equation of mechanics, force = mass $\times$

acceleration, remains true no matter what the size of the units of mass, length, and time."

"Any general connection between the variables can be expressed in the form of an arbitrary function of all the independent dimensionless products of the variables set equal to a constant" [Bridgman, in (7)].

It is a tool which has been used for many years; e.g., in 1871 Lord Rayleigh showed familiarity with its possibilities, and Osborne Reynolds used it not much later (1883) in his investigations in fluid flow.

However, it is only since the turn of the century that any great attention has been paid to it by engineers. Anyone unfamiliar with the subject would do well to read the small book by P. W. Bridgman (1), the several articles by Edgar Buckingham (2), that by H. Lævy (3), and others (11).

It is not the purpose of this paper to discuss at length the possibilities of the use of dimensional analysis (or principle of similitude) in heat transfer calculations. This has been ably accomplished elsewhere (1, 2, 3, 11). Rather is it the purpose to make a plea for a more careful use of this valuable tool in the solving of engineering problems. The material mentioned here is not new, but among engineers loose thinking in this subject has been so common that it was considered desirable to bring to their attention a few points which appear to require elucidation. Among the points to be mentioned are:

(1) What are the dimensions of Specific Heat? They are ordinarily given in engineering literature as $H/M\theta$ or $L^2/T^2\theta$, where $H$ is the dimension of heat, $M$ mass, $\theta$ temperature, $L$ length, and $T$ time. The first group is used if five primary quantities are employable, and the second if only four are to be used. [It is allowable to add heat as a fifth primary quantity if the transformation of work into heat does not exist to an appreciable extent.]

But is either one correct? What is the definition of Specific Heat? According to Roberts (4), "The Specific Heat of a substance is defined as the amount of heat required to raise the temperature of 1 gram of the substance by $d\theta$, divided by $d\theta$, where $d\theta$ is infinitesimal.

The Thermal Capacity of a body is defined as the amount of heat required to raise the temperature of the body by $d\theta$, divided by $d\theta$.

If $s$ is the specific heat of a substance, the amount of heat required to raise the temperature of $m$ gms. of the substance from temperature $\theta_1$ to temperature $\theta_2$ is $m\ s\ (\theta_2 - \theta_1)$, if we neglect the variation of $s$ with temperature. The specific heat of water is approximately unity. The thermal capacity of a body of mass $m$, which is made of a substance of specific heat $s$, is $ms$."

[This also agrees with Edser's definition in "Heat for Advanced Students" (5).]

Frequently the term "Specific Thermal Capacity" is given to this interpretation of Specific Heat. The dimensions are $H/M\theta$.

However, according to Preston (6), the "Thermal Capacity of a body is defined as the quantity of heat necessary to raise the temperature of the body 1 deg. C., and the thermal capacity of a substance is the quantity of heat required to raise unit weight (one gramme) of the substance 1 deg. C."

According to this definition, the thermal capacity of a substance has dimensions $H/M\theta$, but $M$ in this case is not unit mass; it is the mass on which the earth exerts unit weight or force.

"The Specific Heat of a substance is its thermal capacity compared with that of water; in other words, it is the ratio of the quantity of heat required to raise the temperature of a given weight of the substance 1 deg. to the quantity of heat which will raise the temperature of an equal weight of water 1 deg."

Marks' Handbook (7) states: "The specific heat of a substance is the ratio of the heat required to raise the temperature of unit weight of the substance 1 deg. to the heat required to raise the temperature of unit weight of water 1 deg."

With this meaning of specific heat, it ought to have dimensions of zero, for a ratio has no dimensions.

It really makes little difference which type of definition is used —but if the definition is such as to make specific heat a ratio, it is unwise to give it the dimensions $H/M\theta$, or $L^2/T^2\theta$. It may be mentioned that in former years specific heat was ordinarily considered as a ratio, whereas now the tendency seems to be to define it as a specific thermal capacity.

These statements are based on the heat capacity per unit mass of the substance. Frequently a heat capacity per unit volume is encountered in the literature. This would have the dimensions of $H/L^3\theta$.

(2) Let us now consider Specific Gravity. Occasionally in the literature specific gravity is given the dimensions of $M/L^3$. The definition of Specific Gravity given in Hodgman and Lange's Handbook of Chemistry and Physics (8) (and in other books) is: "The ratio of the mass of a body to the mass of an equal volume of water at 4 deg. C."

Marks' Handbook (7) gives a similar definition with the addition of a statement to the effect that the physicist uses water at 4 deg. C. and the engineer water at 60° F. for comparison. With this definition, unquestionably specific gravity should have no dimensions, and would be independent of the system of units in use; and this is the common definition. The dimensions of $M/L^3$ should be reserved for density.

Now the question arises, "Has density the dimensions of $M/L^3$?" According to the physicists' definition of density (8), it is: "The concentration of matter, measured by the mass per unit volume, expressed as grams per cubic centimeter." Notice that this says "mass per unit volume" and thus the dimensions are $M/L^3$. The gram in this case is the gram *mass*.

The engineer frequently gives densities, however, in lbs./cu. ft. But what is meant by lbs. in this case? Is it lbs. mass or lbs. weight, or is there fundamentally such a distinction? Actually, the weight of water is determined on platform scales, and this weight is really a force which has not the dimensions of mass. The number representing a weight is divided by a number representing a volume of water, and the result is written down as the density of the water. Assume that the weight is 62.4 lbs. and the volume is 1 cu. ft. The density obtained in this manner is thus a weight per unit volume, and the dimensions are $F/L^3$. This term has been called "Heaviness" by Church (9). But the definition of density according to the physicist is *not:* weight/unit volume, but mass/unit volume. Thus it would be more correct to say that: "The mass of water upon which the earth exerts a pull of 62.4 lbs. at sea level and latitude 45 deg. would occupy 1 cu. ft."

We are led automatically to point (3). What is mass?

The shortest definition is: "Mass is Quantity of Matter." See Hodgman and Lange (8). But this is not a very satisfactory picture. Perhaps it would be better to investigate this definition further.

Marks' Handbook (7) states: "When acted upon by a constant unbalanced force, a body will move with a uniformly accelerated motion. The accelerations produced in any body by different forces are proportional to the forces, so that $a_1/F_1 = a_n/F_n = \text{constant} = 1/M$, where $F_1$, $F_n$ are the forces applied and $a_1$, $a_n$ are the resulting accelerations. The constant ratio $m$ is known as the *Mass* of the body."

The fundamental equation is, therefore:

$$\text{Force} = \text{Mass} \times \text{Acceleration}.$$

Now if the body is allowed to fall to earth, its weight is the force exerted upon it, and the acceleration is $g$.

Thus Weight $(W) = \text{mass} \times g$, or $\text{mass} = W/g$, where $W$ is weight and is a *force.*

Then the more general equation is:

$$\text{Force } (F) = \frac{W}{g} \times \text{acceleration } (a)$$

or

$$F/W = a/g.$$

Now it has been shown that Weight, with this system, has the dimensions of force.

An illustration would perhaps clear this point. If a man goes to a grocer and buys a pound of sugar, the grocer has no peculiar notions about what is meant. He simply picks up a package which, if placed on platform scales, would register 1 lb. weight. On the scales this sugar exerts a force of 1 lb. on the platform. Also, when the grocer lifts the sugar and holds it in his hand, the sugar presses downwards with one pound weight. This conception of weight is common and is very easy to understand. No difficulty seems to be inherent in it. Of course, since the mass of the body is constant and $g$ varies with location, the weight would also vary with position.

It has been objected that if a spring balance is used to parcel out the sugar it really is a weight which is observed, but if we employ balances we compare masses. This is obviously true, but only because on each side of the balance the value of $g$ is the same. Thus if $g$ is only 16.087 ft./sec.$^2$ at this location the pull of the earth on the "standard pound" would be only one half of its value where $g$ is standard, and thus the weight would be halved. But the weight on the other side of the balance is also halved. Now the mass of a body is its weight divided by $g$, so that the mass is unchanged regardless of variation in $g$. Thus it can logically be said that balances compare masses. But fundamentally we are still comparing weights.

Now *if we limit ourselves to the M. L. T. system,* discussed later in the paper, the standard pound is the pound *mass,* and using balances we get directly from balance reading and volume the numerical value of the density, $M/L^3$.

A paper has been written recently which gives weight the dimensions of mass ($M$), and force the dimensions of weight $\times g$, thus leading to the fundamental equation (not stated) that:

$$\text{Force} = \text{Weight} \times \text{Acceleration}.$$

Do not misunderstand the author's viewpoint, however. There is nothing wrong with such a definition of weight. One can define it in such a manner if he sees fit. But the unfortunate part of our makeup is that we have preconceived notions of what we mean by weight, and, to some at least, weight should have the dimensions of force, *i.e.* $ML/T^2$. Of course, no matter how one defines it, he must be consistent in all his calculations.

Perhaps the simplest explanation of this matter is given by Prandtl (10).

"The effect of gravity on any mass $m$ is that the mass is attracted towards the center of the earth * with a force of magnitude $mg$, where $g$ is the acceleration of a body falling freely, and in medium latitudes is numerically equal to about 981 cms./sec.$^2$ The force $mg$ is called the weight of the mass $m$. As quantities of liquid are often measured by their volume, it is convenient to give a special name to the *mass of unit volume*. It is called the *density*, and is denoted by $\rho$, so that a quantity of liquid of volume $V$ and density $\rho$ has mass $\rho V$ and weight $g\rho V$. The product $g\rho$ is the *weight of unit volume* and is often denoted by $\omega$. This must not be confused with the *specific gravity;* the latter means the weight of unit volume of the substance when the weight of unit volume of water is taken as unity, or what is the same thing, the density of the substance relative to water as unity. The weight of unit volume only coincides with the specific gravity when the units are chosen in a special way (centimeters and grams weight; decimeters and kilograms weight; meters and metric tons)."

"As the attraction $g$ is not exactly the same at all points of the earth's surface, the weight per unit volume also differs to some extent from place to place. For this reason physicists prefer the concept of density which is independent of gravity. In hydrostatic calculations, however, it is convenient to replace the product $g\rho$ by the weight of unit volume $\omega$."

According to the physicist, unit mass was formerly defined as the mass of a quantity of water occupying unit volume. Today the unit of mass is the quantity of matter contained in a certain piece of platinum (the standard kilogram).

(4) In the literature one occasionally finds a dimensional treatment of a heat transfer problem as follows:

*Example*

In forced convection of heat inside a metal pipe, it is assumed that the heat transfer coefficient ($h$) is a function of: diameter of pipe ($D$); thermal conductivity of fluid ($k$); mean velocity of fluid ($V$); mean density of fluid ($\rho$); some viscosity of the fluid ($\mu$); and a mean specific heat of the fluid ($c$).

$$\therefore \quad h = \alpha D^a k^b V^d \rho^e \mu^f c^g; \tag{1}$$

$$\therefore \quad \frac{H}{TL^2\theta} = \alpha \cdot L^a \frac{H^b}{T^b L^b \theta^b} \cdot \frac{L^d}{T^d} \cdot \frac{M^e}{L^{3e}} \cdot \frac{M^f}{L^f T^f} \cdot \frac{H^g}{M^g \theta^g}, \tag{2}$$

* This is not quite accurate: it would be true only if the earth were perfectly spherical and did not rotate. In reality, the direction of the plumb line at places in the northern hemisphere cuts the earth's axis somewhat to the south of the center of the earth.

where $H$ = Heat,
$T$ = Time,
$L$ = Length,
$\theta$ = Temperature,
$M$ = Mass.

Consider $H$ dimensions $\quad 1 = \quad b \quad + g \qquad (3)$

" $T$ " $\quad -1 = -b - d \quad - f \qquad (4)$

" $L$ " $\quad -2 = a - b + d - 3e - f \qquad (5)$

" $\theta$ " $\quad -1 = -b \quad - g \qquad (6)$

" $M$ " $\quad 0 = \quad e + f - g \qquad (7)$

(3) and (6) are dependent.

$\therefore$ There must be two unknowns.

Get in terms of $b$ and $e$:

From (3) $\quad g = 1 - b. \qquad (8)$

From (7) $\quad e + f = g = 1 - b. \qquad (9)$

Add (4) to (5) $\quad -3 = a - 2b - e - 2(e + f)$

$$= a - 2b - e - 2 + 2b;$$

$$\therefore \quad -1 = a - e;$$

$$\therefore \quad a = e - 1. \qquad (10)$$

From (9) $\quad f = 1 - b - e. \qquad (11)$

From (4) $\quad d = e; \qquad (12)$

$$\therefore \quad h = \alpha D^{e-1} k^b V^e \rho^e \mu^{1-b-e} c^{1-b}$$

$$= \alpha \cdot \frac{\mu c}{D} \cdot \frac{D^e V^e \rho^e}{\mu^e} \cdot \frac{k^b}{\mu^b c^b}$$

$$= \alpha \cdot \frac{\mu c}{D} \cdot \left(\frac{DV\rho}{\mu}\right)^e \left(\frac{k}{c\mu}\right)^b;$$

$$\therefore \quad \frac{hD}{c\mu} = \alpha \left(\frac{DV\rho}{\mu}\right)^e \cdot \left(\frac{k}{c\mu}\right)^b.$$

Multiply each side by $c\mu/k$ and

$$\frac{hD}{k} = \alpha \cdot \left(\frac{DV\rho}{\mu}\right)^e \left(\frac{k}{c\mu}\right)^{b-1}. \qquad (13)$$

Thus dimensional analysis has shown that

$$\frac{hD}{k} = \mathrm{fn}_1\left(\frac{DV\rho}{\mu}\right) \cdot \mathrm{fn}_2\left(\frac{c\mu}{k}\right). \qquad (14)$$

Let us examine this treatment a little more closely.

In the first place the wording of the problem is not perfect—as has been shown, there is some doubt about the meaning of specific heat. Why should we use for spec. ht. the particular dimensions $H/M\theta$ rather than $L^2/T^2\theta$ or zero? In the rest of the problem, whenever heat was mentioned, the separate unit of heat was used. Thus, for consistency, it should be used here also and $L^2/T^2\theta$ is automatically ruled out. If, however, specific heat were defined as a ratio, it would have no dimensions, and if introduced with none in the problem, the last group would not be $(c\mu/k)$ but $(c)$. With such a definition of specific heat, the problem should not be stated to involve it as a fundamental variable, but should replace it with heat capacity per unit mass. In general, the statement may be made that the fundamental properties of the material should be substituted in the dimensional treatment; *e.g.*, density, heat capacity per unit mass, etc., rather than specific gravity and specific heat, if these are defined as ratios.

Consider equation (1).

$$\text{Is} \quad h = \alpha D^a k^b V^d \rho^e \mu^f c^g?$$

If the answer, equation (14), is correct, then equation (1) is definitely wrong. The equation could have been stated somewhat differently, but correctly,

$$e.g., \quad [h] = [D^a k^b V^d \rho^e \mu^f c^g],$$

the brackets signifying that the equality is only good so far as dimensions are concerned; in other words, the equation merely states that the dimensions in each bracket must be the same.

Also the jump from equation (13) to equation (14) is not obvious to the beginner at all. Perhaps it could be stated somewhat as follows:

Since no limit has been placed on the values of $e$ and $b$, equation (13) is to be satisfied regardless of the value of either. This can only occur when the summation of the right side of (13) is taken over the entire range of values of $e$ and $b$. A simpler statement of this summation is given in equation (14).

The solution could be written as follows:

$$h = \text{fn}\,(D, k, V, \rho, \mu, c);$$

$$\therefore \quad h = \sum A D^a k^b V^d \rho^e \mu^f c^g$$

or

$$[h] = [D^a k^b V^d \rho^e \mu^f c^g],$$

where the brackets signify merely dimensional equality.

Equate dimensions, and we get:

$$\frac{H}{TL^2\theta} = L^a \cdot \frac{H^b}{T^bL^b\theta^b} \cdot \frac{L^d}{T^d} \cdot \frac{M^e}{L^3e} \cdot \frac{M^f}{L^fT^f} \cdot \frac{H^g}{M^g\theta^g}.$$

Evaluate $a$, $b$, $d$, $e$, $f$ and $g$ in terms of $b$ and $e$, as was done previously.

$$\therefore \quad [h] = \left[\frac{c\mu}{D} \cdot \left(\frac{DV\rho}{\mu}\right)^e \left(\frac{k}{c\mu}\right)^b\right]$$
$$= \left[\frac{k}{D} \cdot \left(\frac{DV\rho}{\mu}\right)^e \left(\frac{k}{c\mu}\right)^{b-1}\right].$$

A typical term is, therefore:

$$A \cdot \frac{k}{D} \cdot \left(\frac{DV\rho}{\mu}\right)^e \cdot \left(\frac{k}{c\mu}\right)^{b-1},$$

where $A$ is a constant for this one term.

Now $h =$ the sum of all such terms regardless of the values of $e$ and $b$.

$$\therefore \quad h = \frac{k}{D} \cdot \text{fn}\left(\frac{DV\rho}{\mu}, \frac{k}{c\mu}\right),$$

the $A$ being absorbed by the functional relation.

(5) The fifth point deals with the evaluation of dimensionless groups. It has been shown that one dimensionless group is $DV\rho/\mu$, called Reynolds' number. In the derivation of the group in point (4), $\rho$ was taken as density with the units of $M/L^3$, where $M$ is mass, not weight. If, however, in evaluating this group we substitute for the numerical value of density the numerical value of the weight per cubic foot of the material, *i.e.*, $\frac{\text{lbs. weight}}{\text{cu. ft.}}$, do we get the correct answer? Fortunately we do, provided that $g$ for that location is 32.1740 ft./sec.$^2$, and the departure from this value is ordinarily too small to consider important in engineering.

But there is inherent in the answer an awkward confusion of terms and systems of dimensions.

It would be well to investigate this point further.

There are two distinct systems of dimensions. Each system may be subdivided into the metric, British, or some other set of primary quantities. To avoid confusion, let us consider only the British system of units, realizing that, although only two systems are discussed, there may be many modifications of each one.

A block of platinum, the "standard pound," is stored in London. The dimensions are $A$ cu. ft. [about 1.3 cu. in.].

*1st System*

*M, L, T*

Unit of length, 1 foot. Unit of time, 1 second.

---

In this system, the block of platinum is defined as the unit of *mass*, (*M*), and is called 1 lb. *mass*.

*g*, measured, is 32.1740 ft. per sec.$^2$

The primary quantities are, therefore, *M, L, T*.

The unit of force is derived from $F = M \times$ accel., and must be such as to give unit mass unit acceleration; *i.e.*, unit of force = 1 lb. (mass) $\times \frac{1 \text{ ft.}}{\text{sec.}^2}$

Now the weight of the object is sufficient to give it an acceleration of *g* ft./sec.$^2$

$$\therefore \frac{\text{unit of force}}{\text{weight of object } (W)} = \frac{1}{g}$$

or, the unit of force $= \frac{W}{g}$

This is sometimes called the *poundal*. However, at present this term has fallen into disuse, and the unit of force is now defined as the force of gravity acting upon a piece of platinum $\frac{A}{32.1740}$ cu. ft. in volume, *i.e.*, a small object.

[The physicist, however, still uses the dyne, which is the c.g.s. equivalent of the poundal.]

$\frac{A}{32.1740}$ Cu. Ft. of Plat.

*2nd System*

*F, L, T*

Unit of length, 1 foot. Unit of time, 1 second.

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In this system, the pull of the earth on the block of platinum, wherever *g* is 32.1740 ft. per sec.$^2$, is defined as unit *force* (*F*), and is called 1 lb. *force* (or weight).

The primary quantities are, therefore, *F, L, T*.

The unit of mass is derived from $F = M \times$ accel., where unit force gives unit mass unit acceleration; *i.e.*,

1 lb. (force) = unit mass $\times \frac{1 \text{ ft.}}{\text{sec.}^2}$

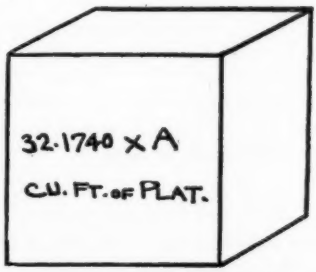
But 1 lb. force gives *A* cu. ft. of platinum an acceleration of *g* ft./sec.$^2$

$\therefore$ 1 lb. (force) = mass of *A* cu. ft. of platinum $\times$ *g* ft./sec.$^2$

$\therefore$ unit mass $\times$ 1 = mass of *A* cu. ft. of plat. $\times$ *g*.

or unit mass = 32.1740 $\times$ mass of *A* cu. ft. of platinum.

*i.e.*




An instructor (name unknown to the author) at Pratt Institute about 1907 used to give this block of material the name WOG, which is merely mathematical shorthand for *W* over *G*.

It has been shown that in the derivation of Reynolds' number in point (4), density was defined as mass per unit volume, *i.e.*, $M/L^3$,

and the 1st system of units was used. But in the evaluation of this Reynolds' number, the heaviness of the material, $F/L^3$, obtained from the second system of units, was substituted in the place of density.

Now it can be seen that, numerically, these two have the same value for a standard value of $g$—dimensionally, of course, they are not alike at all.

There is no question about the dimensions of $\mu$ in Reynolds' number. They can be obtained from the definition of $\mu$ (which is force per unit area per unit velocity gradient), and are $M/LT$, where $M$ is mass, not weight.

If the second system of units had been used instead of the first, the dimensions of density would be $FT^2/L^4$ and the dimensions of viscosity would be $FT/L^2$.

To illustrate the point that confusion does exist in this matter of evaluation of dimensionless groups, the author quotes from an article published May, 1934 (12). The article is headed "Diligent Delver Discovers Disturbing Discrepancy 'tween U. S. and Europe."

". . . Wherever . . . use is made of Reynolds' Number I have found the following universal description of the factors entering into the computation of that number:

$R$ = Reynolds' number, a dimensionless quantity,
$D$ = A cross-sectional measure in feet,
$v$ = Velocity, feet per second,
$\rho$ = Weight density, pounds per cubic foot,
$\mu$ = Absolute viscosity, pounds per square foot per second.

". . . I should like to point out that the use of absolute viscosity and weight density are entirely inconsistent and lead to a number which is certainly not dimensionless. In order to make the number dimensionless, it is essential that if absolute viscosity in pounds per square foot per second is used, then mass density and not weight density must be used."

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It would be better to give the dimensions of $\mu$ as pounds second per square foot. Also, by pounds in this case there can be no error —the pound is automatically the pound force. In addition, $\rho$ is given with a weight density in pounds per cubic foot—this should be the pound mass, as the author of the article pointed out. But the definition of density gives this directly.

The confusion exists because of the switching from the *M. L. T.* system to the *F. L. T.* system. If we stick to either one the confusion disappears.

The author holds no brief for either system, except in special cases. For example, where one is concerned with masses more than

forces, as in astronomy, the first system would be preferable; but if one is interested primarily in forces, as is the case with the structural engineer, the second system would obviously be more convenient.

In heat transfer, however, it would appear that either system is equally good. But the engineer is more familiar in every-day usage with the second system, and the author believes that less confusion would result if he were to adhere to this one. Regardless of which one he uses, however, he should be consistent.

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## ORGANIZATION OF A COURSE IN HEAT TRANSFER

By E. C. RACK

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Everything that happens in the universe may be attributed to the transformation and flow of energy, and since a change of temperature, resulting from the flow of heat, has an altering effect on all properties of matter, it goes without saying that all branches of engineering bring up problems involving the generation, transformation and dissipation of heat. Every engineer must therefore be well trained in the basic laws and have a good working knowledge of the fundamental processes of heat transfer.

The object of these remarks is not primarily an endeavor to outline the methods to be followed in the organization of a course on the subject, but rather to present a brief outline of a few ideas which have been gathered as a result of observations and industrial experience gained in work covering a rather limited portion of the whole territory included in the field of heat transfer. It is a particular desire that these ideas may prove of sufficient interest to elicit a discussion which will be of benefit and value to those who are now working with established courses and also to those who are planning the organization of future courses for study and practice in the art.

Any contemplation of the organization of a course in this subject necessarily involves more than one viewpoint from which it should be considered. Naturally, those observations made by different types of engineers as a result of their practical experience in various industrial pursuits will differ widely, just as the theoretical observations will differ among the various professors and instructors of the institutional as well as the departmental staffs. It is a sincere conviction that the benefits to be derived from symposia of this type will be of much value to the educator as well as to those of us who are invited by you to present the practical views gained as a result of industrial experience.

It is natural to assume that a course in heat transfer considered from the educational rather than the industrial point of view will be divided into two phases, the first phase dealing with undergraduates, the second dealing with the graduate student. In either case, however, the objective of the course and the aim of its instructional staff should be to develop and train men in the fundamentals which they will have to apply to practical use in meeting the demands of industry. This brief discourse will be confined principally to the needs of the undergraduate student. It is believed that the graduate student will have advanced to a plane where he can intelligently coöperate with his directors in outlining his plans and in organizing a course best to suit his ambitions, which may be for research or engineering along industrial or other lines. At the same time it is felt that the generalizations included here will apply with equal emphasis to both classes of student.

We all know that heat is transferred by radiation, conduction and convection. To the industrialist it is only of importance that heat may be made to flow into or out of any one of the various manufacturing processes going on in his plants. For that reason he is primarily interested only in the economical aspects of heating and cooling.

As long as the industrialist is getting an engineer who is properly grounded in the basic sciences, and who has the essentials

of a good working knowledge in the practical application of these sciences to his particular branch of engineering, it is of little concern to him in what sequence the student has acquired the elements of his education. However, to the educator the question of sequence must be a matter of considerable importance. The maximum degree of efficiency of coördinated effort in direction by the instructor and in self-development by the student depends largely on the sequence in which the student is given his study and training in the various bases, as well as the sequence in which he has to apply this basic training. Then for the requirements of this specific course, it would seem logical to plan for instruction along the following general lines of advance.

A concise discussional review should first be given in the fundamental heat flow processes to which the student has already been introduced in his physics course. The logical sequence of review of these processes would fall in the order: conduction, radiation, convection. Emphasis should be laid on the application of these processes to engineering materials and their response and behavior when they are made subjective to the fundamental laws of the heat flow processes. The utilization of materials and industrial processes under steady and varying heat flow conditions should also be included for intensive study by the student.

Since the phenomena of evaporation and condensation are now generally regarded as more or less specialized heat transfer processes, they may well be included for separate treatment immediately following the review of convection. It is realized that there is still much to be done before these two phenomena can be better understood and placed in an exact, concise and systematic form. However, the facts and arguments presented by so many unit operational types of equipment call for a knowledge of the phenomena that it is essential to cover the fundamentals thoroughly in any course on heat transfer.

Also, because of the fact that fluid movement plays such an important part in many industrially important processes, and due to the close relation between fluid motion and convection, an abridged study of fluid dynamics should precede the review of convection. It may also be well to devote some time to practical applications of the theory of similarity to heat transfer problems. It may be argued that insufficient time can be allowed for an undergraduate course in heat transfer to consider the inclusion of these last two subjects in this course. In any case, however, it must be granted that these are important tools which the student should frequently sharpen and keep in condition for future use.

The secondary phases of the course should emphasize the engineering applications of heat transfer to specific problems of varied

nature, such as drying, humidification, refrigeration, direct and indirect heating, etc. This secondary phase should be planned for maximum coördination of the student's work in the mechanics and mathematics of heat transfer of unit operations and equipment and the study and practice he may be receiving in other courses. In this way he will be able to grasp more readily the concept of actualities rather than of idealities.

The functions of heat transfer have become more complex in their industrial applications and, likewise, they are interrelated with all phases of the various branches of engineering practice. For this reason it is well to consider where such a course should best be placed for administrative control so that all engineering colleges may be best served. It is well to plan a course so that no particular emphasis will be placed on the needs of any one department. The functional objective of the instructional staff should be to teach plain and unadulterated heat transfer, and not heat transfer for chemical, electrical, mechanical or other engineering students. By following this plan, the student will be better grounded and more able to acquire and apply the adulteration needed for that branch of engineering and the industry into which he will eventually place himself for specialization.

The intent of a large majority of all undergraduates is to get *a job* after graduation. It therefore seems plausible to assume that the object of the instructor is to produce good engineers and not heat transfer specialists. Furthermore, there are the limits of time, facilities, student intellect, and also other limitations with which you are all familiar, set up around any course. Due to these limitations, and in order that the graduate engineer may best be fitted for his job, it is important that the methods of instruction used by the staff be such that the student will constantly realize that how he studies is of just as much importance and in a sense more important, than what he studies. The graduate student, as contrasted to the undergraduate, is most generally preparing himself to get *the job*, and therefore may be making of himself a heat transfer or other specialist. In either case, however, the purpose of instruction is better to enable the student to develop his ability in independent thought and fully to realize that industry is constantly on the alert for independent thinkers who are able to perform and establish precedent rather than for the man who is prone to rely on and to follow only rules of previous usage.

It is hardly possible than anyone would care to accept an assignment even of trying to outline the ideal engineering educational curriculum. For the same reason and largely due to the personal factor, it would be an impossible task to endeavor to lay out the ideal course in heat transfer. Hence, it must be understood

that the ideal which can never be realized, is not to be implied as being possible of realization. The standard, which may be below the ideal, then becomes the ultimate goal for attainment. Any standard will necessarily vary with institutions, due to personnel and materiel, but in all cases an objective is the teaching of fundamentals and the cultivation of common sense in the student. Before the student has completed his fourth or fifth year of undergraduate work, he is aware of the fact that the work in which he is engaged is only preliminary training for a more or less lengthy period of specialized training which will follow graduation. Then the standard course in heat transfer might well be the one which is best able to instill into the average student a sound knowledge of the practical relationship between classroom theory and laboratory experiments in applications of the basic sciences. The student who has a thorough knowledge of this relationship along with the ability to use common sense, and the ability to express his thoughts clearly and forcefully is the one who will have what after all are the fundamentals of engineering.

The junior, and more especially the senior student, has begun to develop a fairly high degree of interest in his future profession. For this reason, it should be the aim of those organizing a course in heat transfer to lay it out so that the student is made to realize constantly during progress in the course that he is developing another integrant of a coördinated engineering education. Some students may be inclined to feel simply because they are specializing in mechanical, chemical or any other branch of engineering study, that they are preparing themselves in a narrow field of professional training. Every effort should be made in the course under consideration, as well as in other courses, to have it organized and the instruction carried out so that the student will invariably be brought to realize that he is only acquiring a college education with a distinct engineering bias and which must necessarily be broad in order to prepare him properly for what is to come after graduation.

The student is made to realize that mathematics is not given as a practice in the science of correct and accurate thinking, but chiefly for the purpose of making him adept in the use of a convenient implement of engineering which must be applied to the accomplishment of engineering endeavors. Likewise, when the student is receiving his laboratory practice under the proper guidance and in the proper spirit, he must know that the equipment with which he is working is not just a working model of a figure in his textbook or a sketch on the blackboard which was drawn for the sole purpose of illustrating a point. The sketch insofar as the classroom was concerned, is a convenient means to an end. The

sketch may be forgotten, because the apparatus is even more than just a mechanism designed actually to perform in accordance with the classroom theory. The apparatus, as the student should be made to realize, is an engineering arrangement combining more than one principle of the basic sciences, and is part of a larger system with which it will be essential for him to become acquainted and over which he must have power to design, operate, improve and control.

When considered from an industrial point of view the advantages are in favor of the engineer who has developed an understanding of the practical phases of values and costs of personnel and materiel. The course in heat transfer is one of the primary courses in which particular emphasis should be given to the economic factor. A very effective method of making the course worthwhile is by correlation of practical economics with both laboratory and classroom work. It has been said that every decision arrived at during every day of our life is made as an answer to the question of whether the value is worth the cost. Since engineering is, after all, only the practical application of scientific principles to specific problems, it naturally follows that the practical engineer is one who can make economic application of his knowledge. The dissipation, production and transportation of heat costs money and on account of this cost factor, it should be the distinct aim of a course in heat transfer to include in its instructional plan provisions for major emphasis on the economics of practice in the art.

Another essential feature of any fundamental course is that of reports and their preparation. Report writing may be considered as valuable practice in the art of salesmanship, and certainly a student can sell himself best by means of a concise report presented in a manner which shows intelligent designing, liberal thinking and constructive planning. The manner in which the meaning is placed between a capital letter at the beginning and a period at the end of a sentence is worth far more than just the grouping of words which mean little. The student who studies is able to profit by the fact that his instructor is more pleased with the way in which he acquires knowledge than with the method used by the student who has to be taught. Because of the fact that there is more satisfaction in buying than in having been sold, cultivate in the student that faculty of being able to present the results of his work so that you are not sold on the idea, but actually know that the student has performed his task to the best advantage of all concerned.

In the field of heat transfer particularly, much material is continually being added to the existing literature on the subject. The instructor should encourage the student, and more especially the post-graduate student, to keep in close and constant touch with

up-to-date developments by a review and study of the more important literature, much of which comes through in foreign language publications. In this supplementary study the student should be encouraged with aid in developing a facility in distinguishing between useful and worthless material. Some of the published material is in the last class simply because it has been submitted for propaganda purposes. Much of the useless material also includes experimental results which are inconsistent as well as other data of an unreliable or inconclusive nature. A supplementary reading course combined with a few short periods of discussion and review of the methods of attack used by investigators in their major problems should be placed as an essential to any complete course in heat transfer.

Many more features could be mentioned which are recognized in other courses as well as in a course on heat transfer, but it is not the intent of this discussion to go too far with generalities. In summing up, however, the following general principles are outlined with specific reference to the course under consideration. The heat transfer course is one of the essential links between the basic courses and the actualities of engineering practice. The student will already have had a broad picture of the subject matter of the course in his study of the basic sciences. After graduation he must devote his own efforts in strengthening and embellishing this link during the specialization training period. Therefore in order to be of most service between these two phases, the course in heat transfer should be planned, manned and executed so that the instructional methods and the logical arrangement of the course material be such as to accomplish an effective integration of those essentials accumulated during the first phase of the student's training.

## MACHINE DESIGN CLEARING HOUSE

FRANK L. EIDMANN, *Chairman*

### "COURSES IN ADVANCED MACHINE DESIGN"

At the Machine Design Conference which was held at Ithaca in connection with the 1934 meeting of the S. P. E. E., Professor E. S. Ault, of the Case School of Applied Science, presented a paper on "Advanced Courses in Machine Design" (published in THE JOURNAL OF ENGINEERING EDUCATION, December 1934). The same topic also was offered for discussion by members of the Machine Design Clearing House.

We are indebted to the following members of the Clearing House for the accompanying discussions:

F. S. Bauer, University of Colorado
T. G. Caywood, University of Iowa
V. L. Doughtie, Texas Technological College
W. V. Dunkin, Georgia Sch. of Technology
F. L. Eidmann, Columbia University
E. D. Hay, University of Kansas
C. C. Jett, University of Kentucky
E. MacNaughton, Tufts College.
A. L. Townsend, Massachusetts Inst. of Technology

"The main objectives of an advanced course in Machine Design differ but little, if any, from those of an undergraduate course. The development of mental capacity and creative ability are probably of greatest importance.

"The advanced work should naturally begin where the undergraduate work leaves off, but no well defined point marks the change. Probably in no two schools is an equal volume, or same course content required for the first degree. Furthermore, the sequence in which divisions of the subject are presented is by no means uniform. In no two textbooks in Machine Design are the topics presented in the same order. It is not unlikely, therefore, that certain divisions of the subject may be included as undergraduate work in one school and as graduate work in a second school. This may, of course, be only of minor importance if the main objectives of the course are attained. Graduate study, however, implies that further work is being done in the subject; that new principles are being presented and that a clearer understanding

and more extended application of the fundamental principles are being developed. If undergraduate courses, therefore, were more clearly defined as to scope and content, graduate courses would have a more definite meaning.

"The advanced course will require knowledge from many fields in addition to that of actual design. In general, some familiarity of the basic principles in many fields is a prerequisite for successful design work. For example, gas engine design cannot proceed very far before a knowledge of certain basic laws in engineering thermodynamics will have to be applied. Similarly, the principles of strength of materials, metallurgy, statics, dynamics, economics, and many others must be applied. Indeed the design of a complete unit provides a most excellent opportunity for the most thorough review and training in the basic principles and laws of these fundamentals."

"In discussing advanced courses in Machine Design, it is assumed that the students are quite familiar with the rational analysis of the fundamental principles of mechanics used in designing machinery. Rational analysis should be closely adhered to in elementary and regular courses and the application of empirical formulae and experimental data left to the advanced courses. It is well that the beginning students in machine design become mathematically minded and that their confidence in rational analysis is strengthened. When and only when the students have this perspective view of machine design will they be able to make much progress in the design of actual machines that will function. I should like to make it clear that the solution of a number of highly technical problems concerning a machine is one type of course and the design of a machine that will actually function is entirely another type of course. I am of the opinion that advanced purely theoretical analysis of machines without incorporating the results of such analysis into completely designed machine or part is of interest to only a small percentage of the average senior class.

"The other extreme might be to completely design and build a simple machine and test it under actual working conditions. This would not be advisable for many reasons that are obvious to those teachers who are familiar with the limitations of students as mechanics and with the manufacturing equipment found in the usual engineering laboratory.

"With these points in mind I have found that the most interest can be aroused in the average student by avoiding both extreme plans and to incorporate in advanced courses the complete analysis of well designed actual machines, checking up all manufacturer's data on the machine. When using well designed machines for this

purpose, I have found that the results of rational analysis agree very closely with the actual machine under investigation. I know of no better way to strengthen the confidence of a student in his own designs than to have him discover that if he were designing the machine which he is analyzing, he would make it but little different.

"To inspire the student's interest in Machine Design is quite essential but this is not enough. He must acquire technique in design and gain confidence in his work. He may hear instructive lectures and see interesting pictures illustrating design and manufacturing but this alone will not develop his technique or inspire self confidence. He must actually apply (to a limited extent, of course) those fundamentals in a design then have it brought home to him that his newly created machine checks very closely with similar existing successful machines."

"I do not favor an advanced course in Machine Design in a four year curriculum. In my opinion the advanced course should be given as a graduate course, preferably as an option.

"It should include a thorough treatment of advanced strength of materials as applied to machine parts, and advanced dynamics of machinery, and should be supplemented by the actual design of a complete machine. The design should be developed rationally with suitable modifying factors from experience to make the design a practical one. Consideration should also be given the shop processes, adaptability to machine tools, design and use of jigs and fixtures, cost of production, sales appeal, and the prior art as evidenced by patents."

"Since there are various ways of teaching Machine Design and even many types of courses labelled 'Machine Design,' it would behoove one to come to a conclusion as to what is machine design. The first course in thermodynamics studied by the student, is more or less the same at any institution. He usually studies the same subjects and principles. But it is not so with the course in Machine Design. Machine Design courses as given in the 4-year mechanical engineering curricula will depend a great deal upon the teacher, his training both in and out of school; the preliminaries or fundamentals which his students get at the particular institution, and type of text book. Some courses in Machine Design are advanced work in strength of materials; some courses consist of practice in the use of hand books and company literature labeled 'engineering data'; while still others are courses in drawing. In some cases, if time permits, Machine Design courses cover all three of these phases.

"Then let us define Machine Design as the application of the principles of mechanics to the design of machinery keeping in mind the manufacture, usefulness, maintenance and cost of the finished product. If we accept this definition then an advanced course in Machine Design should follow advanced courses in mechanics such as theory of elasticity, stress, concentration, plasticity, vibration, etc.; and advanced courses in metallurgy, shop and probably economics. So it seems that this advanced course in Machine Design will by necessity be put off until the later part of one's educational training. Then the question arises as to whether there will be time for such a course and whether it will be beneficial to the individual.

"If advanced course in Machine Design means the design of another piece of machinery with all the drawing, specifications and catalogue assembly without the application of advanced fundamentals, I believe that advanced courses in mechanics, which have been mentioned, would be of more value to the individual intending to enter design work. It is my belief that the individual with training in advanced mechanics is needed in industry and that he will be better prepared to cope with new ideas and methods. In conclusion, let the student study advanced course in mechanics first and if time permits then a course in advanced Machine Design would be helpful."

"I do not believe that advanced courses in Machine Design have much of a place in undergraduate instruction. It seems to me that such courses require men of much more design experience than the large majority of our design teachers have had. I can think of several teachers who would be successful with such courses, but there are many others who would not be able to put it across. Such courses, in my opinion, should be limited to thesis studies and should be given only to those students who have shown unusual ability in previous design courses."

"I heartily agree with Professor Ault. First of all, a thorough course in the elements of Mechine Design is essential and should precede any other course in which the designing of machines is studied. This should be a course of an analytical type involving the solution of problems by rational methods, and at the same time the student should be given the variations which may be encountered in practise modifying the ideal conditions assumed to exist when the rational formulas were developed. Such a course should include lecture, recitation, and problem periods but little or no drafting.

"At the end of such a course the student will have about the same preparation that a student in structural engineering will have

after having completed his course in elements of structures. He has just received the basic preparation for a design course.

"The first course in advanced Machine Design should give the student the opportunity to gather up the machine components which were considered in the course of elements of Machine Design and incorporate them into one or more units or machines in which he will meet with the interrelation of the elements and learn something about the limitations imposed when the elements are so related. Such a course, if the time is limited, should consist of a complete analysis of the machine, order of procedure to be followed in this development of the analysis and design, first class freehand sketches of elements and associated parts of the machine, computations determining sizes and shapes, relative costs, and materials which might be used in the construction of the various parts. At best such a course will be somewhat sketchy unless a great deal of time be allotted to it, because of the many factors which should be considered if the solution of the problem under consideration is to be at all complete.

"Following the usual sophomore or junior course in mechanisms and the course in dynamics as taught by the Department of Theoretical and Applied Mechanics, and advanced course in the Mechanics of Machinery or Dynamics of Machinery, with some emphasis upon the subjects of vibrations, inertia effects, etc., should be included in the schedule of the student majoring in Engineering Design. The training offered by the above courses is especially valuable for students who wish to specialize in such fields as gas engine design, Deisel engine design, turbine design, etc.

"I have always believed that the successful machine designer must possess the creative instinct common to writers, composers, artists, and architects. In order to determine whether the would-be designer of machines possesses this faculty or not, I believe a short course in inventive design should be taken as soon as possible after the first course in the Elements of Machine Design. If the student does not posses this faculty to a considerable degree, it is my opinion he will at best be nothing more than a copyist and never a real designer or creator of machines.

"For the student who proves that he possesses the faculty of invention or creation, I would suggest that his final study or thesis should include the complete study and design of some machine, and that this study should include selection of materials, methods of manufacture, economics of the design, ease of maintenance, servicing, etc., appearance, sales appeal, patent features, possible future trends or developments, in fact all those features which might be considered under such a heading as philosophy of design."

"Items usually not covered to any great extent in the elementary courses in Machine Design are: (1) special stress and deflection analysis, (2) vibration, (3) design involving elevated temperatures, (4) production costs, including shop processes, finish and material selection, (5) sales appeal of product as to form and color, (6) safety of operator, (7) ease in control of machine, (8) quietness of operation. Therefore these items offer material for courses in advanced Machine Design. The first three items can probably be covered most satisfactorily in a theoretical problem course. The remaining items can be covered very well in a project course in which the student develops a single machine. In this work it is highly desirable that there be close correlation with the shop laboratories. The design of jigs and fixtures and a consideration of the capabilities and limitations of the shop tools would be an important part of the project. Very little drawing board detail work should be included in an advanced design course. A considerable part of the problem can be covered by written specifications and sketches."

"As I have previously mentioned, I am much concerned as to the general misconception of what constitutes Machine Design. Many people, including some who should know better, seem to think that Machine Design is largely a question of making drawings. They have but little concept as to real scope of Machine Design as we know it. The undergraduate courses in Machine Design at this college are, in a very real sense, courses in *applied* Applied Mechanics, *applied* Applied Kinematics, and *applied* Materials. The major portion of the time is spent in analysis and computations, and the actual delineation of completed problems is reduced to a minimum. In the advanced courses in Machine Design more time is allotted to the drawing process, since the problems in advanced Machine Design, as would be expected, are more comprehensive in nature and thus require assembling of many component parts on paper.

"From the foregoing you will gather that I am not wholly in sympathy with the name Machine Design, and at the present moment am partial toward some other term. I favor inclusion of the word analysis, so that the title would be: 'Machine Analysis and Design.'"

"Professor Ault states several reasons for giving advanced work in machine design, the most important of which seems to be to awaken and develop the creative ability of the student. It seems to me that if the creative ability of the student is once aroused the remaining reasons will be very easily taken care of.

"By design is here meant the complete design and actual working drawings. A man may know a great deal about dynamics, kinematics and strength of materials, but until he has actually delivered the goods in the way of practical application his knowledge amounts to naught.

"The author discusses the limitations of the two types of courses, informational and analytical. What we need is a synthetic course. Let the student obtain his basic information wherever possible, from the instructor, or elsewhere. Let him analyze machines of a character similar to his problem. Then the real job consists in making the various elements conform to the requirements imposed in his particular problem and in putting the same together in order to make a well designed whole.

"It is, of course, difficult to find sufficient time in the curriculum to introduce an advanced course of this kind. However, if we have students of the right type who are not behind in their other work and who desire some work of this nature, such a project might serve as a thesis. One of my students has just finished the design of a centrifugal pump. He did a very good job without taking up a great deal of my time.

"Probably the best way for a student to learn advanced machine design is to work in some good commercial drafting room, especially one which is connected with a shop."

# The T-SQUARE PAGE

DEVOTED TO THE INTERESTS OF THE DIVISION OF ENGINEERING DRAWING

FREDERIC G. HIGBEE, EDITOR

*Beauty in Design:* Members of the S. P. E. E. who attended the dinner meeting of the Division of Engineering Drawing at Purdue in 1931 will recall the excellent papers on "The Field of Graphic Art in Engineering Education" by Professor Thomas E. French; "The Artistic Side of Engineering Design in the Manufacturing Industry" by Mr. F. C. Dohner; and "Art in Engineering Structures" by Professor N. D. Morgan. All of these sounded a new note in the area of engineering drawing; they were pioneering adventures into a territory unexplored by engineering drawing teachers. To what extent these views—which boldly advanced the belief that teachers of drawing should support and teach beauty in design as an integral and indispensable accompaniment of drawing—were sound may now be judged by their widespread acceptance in industry. Only today has current literature in art, in industrial design, and in the more popular and widely read magazines caught up with a belief expressed and endorsed by teachers of engineering drawing five years ago.

Important as this element undoubtedly has become, teachers of engineering drawing are still faced with the problem of how to incorporate such teaching into an already crowded course of drawing, and even assuming time were available there yet remains the somewhat baffling problem of *how* to teach beauty in design. Opinion naturally differs with respect to the actual accomplishment of such a desirable end, but there seems to be a fairly general belief that drawing departments should make the start and that the finish will come only by consistent and coöperative effort throughout the entire engineering curriculum.

*The Annual Competition in Engineering Drawing:* Information about the annual competition and the requirements for entries may be found in the March 1934 JOURNAL, page 488. Drawings entered in the competition may be forwarded immediately to the Chairman, Drawing Competitive Committee, Georgia School of Technology, Atlanta, Ga.

# VALUE OF DRAWING IN THE ENGINEERING CURRICULUM *

By CARTER C. JETT

Professor of Machine Design, University of Kentucky

The planning of an engineering curriculum is simply a problem in engineering design. The curriculum is a means to an end. It is a tool with which we shape the raw material, namely the freshman, into the finished product, the graduate.

With this analogy in mind, the main question is, "How shall we finish and equip the graduate in order best to prepare him for his life's work."

This is a difficult question to answer unless we know what will be required of the graduate when he takes his place in industry. It is evident that first-hand information on this subject is highly beneficial to the instructor, but first-hand information in all the major fields of engineering is not possessed by all instructors. Every instructor, however, may obtain second-hand information on these requirements from those who have worked in the various fields. The experiences of faculty members and of former graduates furnish such knowledge.

The major fields of activity for engineers may be listed as follows: Design, Construction, Operation, Maintenance, Sales, Purchasing, Testing and Research.

It is readily understood that we can not turn out a finished product (or graduate) who is proficient in any major field. The graduate should be resourceful and able to work his way up to higher grades of proficiency. The training given to a student should be so fundamental in its character as to enable him readily to adapt himself to new conditions and to change from one field of activity to another, especially when openings are not available in his chosen field. A young engineer should soon learn that it does not pay to be too particular and fastidious about the kind of a job he undertakes. This shows that training for a specialty is out of order. A general training is the best, after which the special qualifications can be developed.

Nobody wants to hire a man who can not produce results. The engineer must have creative ability which comes from a creative imagination. He must be able to express his ideas. Let us briefly

* Presented before a meeting of the Kentucky Section, S. P. E. E.

consider each of these major fields of activity in the order previously listed.

First comes the designer. Of all engineers he is the one who should be most proficient in drawing. Let any one who doubts this statement try to hold a job in some drafting room. An engineer engaged in construction, whether of foundations, buildings or machinery, should also know how to make drawings and sketches from which other people can work. A misunderstanding of his instructions may lead to costly errors in the finished work. The cost of removing and rebuilding a few yards of concrete would pay for a few more semester hours of drawing before the engineer of construction left college. He must also be able to understand and interpret the most complicated drawings made by others. In order to acquire this ability he must have had good experience in producing drawings.

The operating superintendent of any plant must have a knowledge concerning the design of new equipment and plant lay-out, together with the changes in his present equipment. He must study and devise new methods of production. He must communicate his ideas to the engineering department which in turn may consist of a lone draftsman. It may not be absolutely necessary that the superintendent have a knowledge of drawing, but such a knowledge is a valuable asset.

When it comes to maintenance, probably most of us have had experience with some master mechanic, who may have two or three draftsmen working in his office, and who can not explain to his men the nature of the things wanted. Numerous illustrations could be cited, but time will not permit. Look at the time and trouble which could be saved if every master mechanic knew how to use a pencil.

In the selling game my experience is limited. However, it seems natural to suppose that a man selling mechanical equipment should analyze the situation of his customer and be able to make certain lay-out drawings showing the installation of new equipment. I have known of a number of salesmen who carried their drawing boards with them.

It may not be necessary for a purchasing agent to be a proficient draftsman but there have been instances where purchasing agents were recruited from the drafting room. He certainly should know the minute details of the things he wishes to buy and all such details are shown on the drawings which he sends out.

Any man engaged in testing and research should be able to design and draw his own devices and equipment.

The foregoing remarks apply principally to the major fields in which a knowledge of drawing is of primary importance. Such a

knowledge is of at least some importance in every field of engineering. An engineer should read the technical magazines and be able to understand the drawings contained therein. A knowledge of drafting will enable him to appreciate more fully such drawings and descriptions.

They say every engineer should cultivate some hobby. Such a hobby with one of my friends, is that of raising chickens. He also happens to be a good draftsman and an employer of draftsmen. No doubt his ability along this line has served him well in designing his chicken houses and poultry equipment.

Another hobby may be that of sail boats. How can we coordinate the center of effort with the center of lateral resistance without a knowledge of drafting? Sometimes we can not even do it then. How can a billiard player explain his shots without the aid of a pencil? Also, in an engineer's contacts with people in various walks of life his drafting room knowledge is frequently a great help in clarifying his ideas.

Thus we see that in no matter what field of engineering one may be engaged, he will be working with draftsmen, be an employer of draftsmen, or he must have a thorough understanding of the product of the drafting room.

In order to teach this subject no expensive apparatus is required. From an economic point of view the subject can be taught with very little cost to the school.

The only conclusion to be drawn is: Give this important subject its rightful place in the engineering curriculum.

# EXTRAVAGANT DEMANDS FOR SOCIAL SCIENCE IN EDUCATION

By L. E. AKELEY

Dean Emeritus, University of South Dakota

There is considerable evidence pointing to the mobilization of a rather powerful piece of educational propaganda, to which no group of professional people, including engineers, can be indifferent.

Near the beginning of the depression the American Historical Association appointed a commission to investigate the question of Social Studies in the schools. This commission has issued a number of small volumes of its report. The 16th volume, entitled "Conclusions and Recommendations," reveals the character of the whole drive quite clearly. While this report contains some excellent educational recommendations in the details of the project, its proposition as a whole is such that one can not be rash in assuming that the membership of S. P. E. E. will consider it nothing short of being a menace.

The Commission at the outset outlines what it calls the "Frame of Reference" which is intended to give the limits within which the new educational movement is expected to develop. The character of this so-called "Frame of Reference" may be fairly well indicated by the following quotations.

"Under the moulding influence of socialized processes of living, drives of technology and science, pressures of changing thought and policy, and disrupting impacts of economic disaster, there is a notable waning of the once widespread popular faith in economic individualism, and leaders in public affairs, supported by a growing mass of the population, are demanding the introduction into economy of ever-wider measures of planning and control."

"Cumulative evidence supports the conclusion that, in the United States as in other countries, the age of individualism and *laissez faire* in economy and government is closing and that a new age of collectivism is emerging."

"As to the specific form which this 'collectivism,' this integration and interdependence, is taking and will take in the future, the evidence at hand is by no means clear and unequivocal. It may involve the limiting or supplanting of private property by public property or it may entail the preservation of private property extended and distributed among the masses. Most likely it will issue

from a process of experimentation and will represent a composite of historical doctrines and social conceptions yet to appear. Almost certainly it will involve a larger measure of compulsory as well as voluntary coöperation of citizens in the conduct of the complex national economy, a corresponding enlargement of the functions of government, and an increasing state intervention in fundamental branches of economy previously left to individual discretion and initiative—a state intervention that in some instances may be direct and mandatory and in others indirect and facilitative. In any event, the Commission is convinced by its interpretation of available empirical data that the actually integrating economy of the present day is the forerunner of a consciously integrated society in which individual economic actions and individual property rights will be altered and abridged," pages 16 and 17.

"The critical character of the present epoch in American and World history, with its social stresses and strains, makes especially imperative the organization of a special program of social science instruction coherent and continuous from the kindergarten through the Junior College and the articulation of the program with a program of adult education," page 48.

This, taken in connection with the "Frame of Reference," means that a program of indoctrination of the youth from kindergarten to university is going to displace still more of that education in fundamentals which colleges of engineering have rather vainly expected to find in some degree in the possession of their incoming freshmen.

The Report goes on to say: "The writers of textbooks may be expected to revamp and rewrite their old works in accordance with this 'Frame of Reference' and new writers in the field of the sciences will undoubtedly attack the central problem here conceived, bringing varied talents and methods and arts to bear upon it." "Makers of programs in the social sciences in cities, towns, and states may be expected to evaluate the findings and conclusions of this report and to recast existing syllabi and schemes of instruction in accordance with their judgment respecting the new situation," page 147.

"For great university departments to refuse to relate their work to the tasks of education will scarcely be tolerated in a closely integrated economy managed in the interests of society; for teacher training institutions to fail to make full use of social knowledge and thought in the formulation of their policies should be regarded as a gross neglect of duty," page 110.

There is no need of any effort to stimulate the imaginations of members of S. P. E. E. respecting the meaning of this imposing vision of the Commission on Social Studies. Enough has happened

in educational history of rather recent years fully to interpret these quotations.

There are few aspects of the present world crisis which would not be barred as appropriate issues for discussion in the JOURNAL OF ENGINEERING EDUCATION. Those few, however, should concern everyone who is interested in educational problems. The Conclusions and Recommendations of the Commission on Social Studies from which the above quoted abstracts have been taken are inspired quite obviously by the depression situation. It is the contention of this paper that they are misleadingly inspired.

The aspect of the situation which should vitally concern education is the futile voluminousness of the current discussions concerning it, and the bewilderment which all the futilities are generating in the minds of serious and thoughtful people.

A recent straw in the wind indicative of this bewilderment is Mr. William Allen White's statement to a press association to this effect, "I am without rudder, anchor, or compass. I do not know what is the matter."

Now just that very thing is what is most seriously the matter, viz., that such people as he all over the country are bewildered and because they are bewildered, there is so little leadership of intelligence and character.

Unlimited discussion, never reaching a goal, wrecked the intellectual character of Athens in the age of Socrates, giving immortality to the word sophist. Such wild license in discussion will no doubt wreck any civilization, the intellectual disaster being followed by the ruin of national morale. Discussion seems to be the bane of revolutionary periods as was the case in John Locke's 17th Century of the English Revolution. Locke entertained a discussion group of five or six friends who met in his chambers in an attempt to solve some of the vexed problems of human behavior in that troubled age. Locke was impressed with the inability of the group to reach conclusions compelling assent on the part of each member, to say nothing of what the effect of it all might have been on the public at large. To solve this discussion-group problem was the motive that drove Locke to that philosophic enterprise which ended in the publication of his immortal contribution to philosophy, "An Essay on the Human Understanding." The irony of it all was that, so far from giving discussion groups power to reach cogent conclusions, through a knowledge of the limitations of the human understanding, this famous philosophic project raised questions which have kept discussion going, now almost three centuries, leading to nothing but ever new starting points for further discussion. Mere discussion breeds more discussion.

But science solved John Locke's problem. Scientific men have

their discussion groups, where discussion is carried on in their national and local society meetings and through their journals. Science has solved the problem by adding to this social approach to problems the individual approach. Ultimately discoveries are not made by groups, but by individual scientists in individual laboratories and studies, by individual effort. In the end the fruits of individual insight, interpretation and experiment are accepted by the group. This achievement is something new under the sun and belongs exclusively to this modern age.

Charles S. Pierce wrote one sentence which could never in all human history have found expression before the middle of the 19th century. It was this. Truth is that "opinion which is fated to be ultimately agreed to by all who investigate." The idea of an opinion that is fated to be *agreed* to by *all* who investigate!! That statement is the most significant mile-stone in the intellectual history of the race.

The fact that the physical and material sciences have made that statement meaningful makes those sciences the basic field for the training of all who are to become investigators.

These sciences have reconciled the individual with the social approach to all problematic situations. Individual free initiative and social compulsion are not antagonistic, but complementary and mutually supporting. They are what Ex-President A. Lawrence Lowell calls conjugate principles. Which of the two principles will play the dominant role in any period depends upon frontier conditions. People who hold that social compulsion in the form of national economic planning is to dominate industrial life base their convictions on the alleged fact of the disappearance of the frontier. The frontier has not disappeared. It is only temporarily closed. Hence the domiance of collectivistic ideas. That is only temporary. The reopening of frontiers will again make individual free initiative the prevailing outlook. The scientific and inventive frontier is the richest ever opened up to man.

The first stage of the so-called industrial revolution was a mechanical and tool revolution. Steam was the source of power. It opened up all kinds of new frontiers. Its social, economic and political effects were far reaching, producing many very serious problems in the social field.

The electrical stage of the new order permits the correction of some of the bad effects of the first stage of it. With steam, power could be transmitted no farther than a leather belt could reach. Electricity permits decentralization with significant social changes possible.

The third stage, the chemical revolution, so far as its power to open up new economic frontiers is concerned, has just begun its

career. It promises economic and social effects that can possibly solve most of the grievous problems which social planners are laying to the alleged depravity of the physical and material sciences.

The thing we are going to do, in spite of all talk of a scientific holiday, and of social planning and collectivism, is to endure a great many of the consequences of progress until the so-called industrial revolution shall have been completed and rounded out into a well integrated system, a kingdom in which man will be ruling nature and himself.

Meantime, science and invention will point out the richest economic frontier ever envisaged, and free individual initiative will advance to its conquest, and social planning and collectivism will play a diminishing role.

One trouble today is that many who investigate have received no intimation of physical science's reconciliation of the conjugate principles of free individual initiative and social compulsion, of the solution of John Locke's problem. These people know so little of physical science that its frontier possibilities are absolutely disregarded.

This writer has not so much of a quarrel with social scientists as with the physical scientists who have made such ineffective use of the prominent place they have held in educational programs for the last fifty years. The ignorance on the part of social scientists of the frontier-opening role of physical science can be laid on the doorstep of instructors in physics and chemistry.

Some men naturally seek a protective environment, protective of their interests, their feelings, their prejudices. They cuddle up to that environment in pathetic infantilism. Other men seek an environment which will not protect them except as they change it. Nature is the only mother who refuses to coddle her children, whose categorical imperative is the achievement of a real adulthood. Mother Grundy, the symbol of the protective social environment, gives men assurance of ease in Zion on condition of the surrender of individuality and freedom, which were the focal points of the 17th Century Liberalism of the England of John Locke. Individuality and freedom asserted themselves in science, business enterprise and in all the problems of the human spirit. The traditions of liberalism and of the physical and material sciences are one and the same. The futilities of contemporary liberals come from their forgetting their great traditions.

In accordance with this interpretation of modern history, the physical and material sciences should be the basis of under-graduate education. This does not necessarily imply any criticism of the place which the social sciences hold in the present day college curricula.

But it should be a reinvigorated physical science instruction. Nature's efforts to force her children to become men is most highly dramatic. All the instincts of infantilism resist her. How few teach physics as a succession of dramatic episodes, which is just what physics is in the most significant sense of the word *dramatic*. The teaching of physical and material sciences should epitomize what Professor Bridgman of Harvard has so effectively described as the Struggle for Intellectual Integrity.

No wonder men have no rudder, anchor or compass, and that their sails are full of the winds of social and economic discussion.

# TEACHING LITERATURE TO ENGINEERS

By A. C. HOWELL

Associate Professor of English, University of North Carolina

The problem of interesting engineering students in literature is one that faces English teachers in many technical colleges and will undoubtedly grow more acute as new curricula calling for more humanistic content gain in popularity. If the course is to be a success, it must be not only instructive but entertaining. It need not degenerate into a show, but it should hold the interest of students and give them value received for their time and effort. The aim of the teacher of literature in a technical school ought to be to hear students say after the course is over, that it has furnished pleasant hours for them and has opened new vistas and avenues of interesting speculation. Naturally such a course cannot be the usual dry survey of literature taught to liberal arts students, nor can it go very deeply into matters of æsthetics. It cannot last as long as the required literature course in the college of liberal arts; usually it is organized for one quarter or semester. The problem, then, that faces English teachers is to plan a course which will meet these requirements and at the same time justify itself to students and to the administration.

One such course, used at the University of Illinois, is presented in an article in *The English Journal* for April, 1931, by Professor B. L. Jefferson. I should like to discuss the plan which has emerged after numerous experiments at the University of North Carolina. The primary objects of the course are to present stimulating ideas from great literature and to show how these ideas have been woven into the fabric of our thinking; to fit these ideas into the historical background of the modern world; and finally to give the student a speaking acquaintance with some great writers. Since the problem of interest is the most difficult to meet, I shall begin by offering suggestions which I have found helpful in producing and maintaining this interest.

## II

The first day of class affords an excellent opportunity to present the aims of the course and to catch the interest of students who may wonder what literature can do for them. Usually some such ideas as the ones given in the following paragraphs will set students to thinking in the right direction.

Let us begin with some experimental definitions of literature. Of course in the last analysis, all written records are literature, as scientists use the term when they speak of the literature of a subject. Naturally, however, this definition will hardly serve for literature in the sense in which we study it. But we must not forget the fact that literature is a record, recording for us in vivid language both the past and the present, laying open for us the mind of man in all its manifold aspects: as history, as story, as experience, as idea, even as soul; in short-story, novel, play, poem, essay. But unlike an annual report, which is record pure and simple, literature is *experience*. Facts it does record, like the report, but it goes further than facts: it records action, feeling, emotional states, changing points of view. It shows how men live and have lived since they became articulate, how they think, feel, love and hate. And in showing these things, it prepares the discriminating reader to meet and deal with the situations he is likely to face in his life; it forms our opinions, it educates us. Literature, then, is a *record of life* past and present, perhaps even of future life. For human nature changes but little. The same emotions that stir us: hate, love, greed, ambition, self-sacrifice, loyalty, moved the Greeks and Romans. Whether we read the story of Cleopatra or of some modern siren, we find that men and women may change their clothes but not their natures. (The fact that this statement is open to argument makes it all the more valuable in an introductory talk. It may have repercussions later.)

Therefore, because literature furnishes us with the materials for an *interpretation of human nature,* it is as important a study for engineers in this day as mechanics. The engineer is concerned not alone with the forces of inanimate nature but with the forces of human nature. So he learns something when he looks into Hamlet's soul and sees him thinking aloud through the great temptations which assail us all—cowardice, procrastination, self-destruction, envy, revenge, and hatred. When he meets Becky Sharp, the adventuress, he learns about women from her, without breaking his heart or his pocketbook. Milton might teach him the same things, or Plato, or Montaigne, or Seneca. The point is that literature teaches us about men and women and thus opens for us a field not covered in theoretical courses in engineering.

But in addition, literature puts us on speaking terms with the great minds of the past and enriches our cultural heritage. It releases an inner light which illuminates our minds, our actions, even our speech. It gives its possessor a certain poise and urbanity not to be scorned by the technical man in our generation which is learning that men are more important than machines. For these rea-

sons and others the authorities have concluded that literature has something to offer to every college-trained man.

Let us glance rapidly at some of these values of the study of literature. First, since literature is an *art*, it furnishes a means of self-expression for the reader. All art is self-expression and self-realization for the artist. Vicariously it is the same for the layman, furnishing him with inspiration, and experience. We cannot all travel, or have incredible adventures, or be moved to song by the west wind or a Grecian urn, but we can have these experiences through literature. We cannot all put in words our deepest thoughts, our spiritual exaltation, but these half-felt ideas, these universals, which every man thinks and which seem to belong to all men, we can recognize when we read "What oft was thought, but ne'er so well expressed."

Again, since literature is a *fine art*, it appeals to the æsthetic sense, as surely as a great bridge or a smoothly humming generator does. It contains beauty, rhythm, artistic form; and since it is expressed in language it requires the least special training for its appreciation. Through its study we develop taste; by means of judicious comparisons we learn to choose the better, to be discontented with the cheap and the childish. Moreover this taste and this knowledge, the stamp of the educated, as opposed to the skilled, man, finds expression in more animated and intelligent conversation. Several of my students have expressed to me their delight at their ability after studying literature to converse intelligently about books; some have even found it profitable in making contacts.

Minor reasons for the study of literature are that it furnishes an economical means of enjoying one's leisure. In these days the library competes successfully with the movie palace as a place to spend the evening. For,

> When lands and goods are gone and spent,
> Then learning is most excellent.

Dr. Edgar Knight puts it very clearly in a recent address:

> The most substantial possessions in this world are not lands and goods. These are always within the reach of depressions and bankruptcies and banking thieves and moths and rust. The only imperishable and indestructible possessions that remain with human beings after they have been robbed or "stripped of those others falsely so called" are the love of books, of reading, and the habit of reading. These possessions defy adversities; they outlive calamities. The "benignities of literature," as James Russell Lowell calls them, are inalienable treasures.

And then, according to student opinion, literature increases one's knowledge of words, of language, of ideas with which to work. This service of literature, which is indefinite but infinite, cannot be

overlooked by any professional man whose position requires frequent speaking and writing.

Finally literature furnishes what the late Dr. Edwin Greenlaw calls a *Principle of Action.* In the old schemes of education this service was performed by the classics; now it must be done by literature. In a stimulating paper in *The English Journal* for April 1924, he points out that "every great period has had its special philosophy, its invisible principle," and that these are to be discovered in its literature. Today when the sciences overshadow the arts in our curricula, literature must offer intelligent criticism and interpretation based upon the great ideas of the past stored up in the living souls of great books. Education, he goes on to say, should not be merely "an ornament, a convention, an elegant leisure, not even a means to business success." It must be "a knowledge and a passion."

> Now this knowledge and this passion are the very stuff out of which literature is made. Literature knows not time nor place nor nationality. It is the record of the human spirit as that spirit has confronted the facts of experience and of nature. . . . Three books there are, great volumes that constitute the course: the Book of God's Word, the Book of God's Works, and the Book of Man: The Bible, science, and literature. And in this Book of Man, this Bible of the Human Spirit, the masterpieces of literature, old and new, short and long, are but chapters or paragraphs or songs.

Literature has in it this invisible principle which can quicken our souls and keep us forever from being mere automatons, only capable of feeding and clothing the body. It can enable us amid the roar of machines to hear the still sad music of humanity, to perceive above the laws of physics and chemistry the laws of beauty and indeed of life itself.

## III

Ideas such as these are bound to stimulate thinking, perhaps open disagreement. But disagreement will be the life of the course. And this brings up the second method of arousing and maintaining interest in a course in literature, class discussion. Classes should if possible be limited to twenty-five or thirty students so that every man may have the opportunity to express himself freely on the ideas brought out in the selections discussed. Lectures should be very brief and should be largely explication of the text or biographical and historical information which will throw light on it. The class hour should be made pleasant with jokes, side bits of human nature from the lives of the authors, comparisons with modern instances or material from the day's news. It should,

to use the words of a student, be a pleasant hour of recreation after the dry courses in pure or applied sciences. But this pleasantry should not overshadow the permanent values to be stressed in the course.

It has been my experience that students are stimulated by mild doses of philosophical ideas, and I often send them to Will Durant's *Story of Philosophy*, or some of the books in the "Today and Tomorrow" series. The nature of reality, the metaphysical world, the political theories of Hobbes, Locke, Ruskin, and Mill, the development of the idea of progress, and the nature of God—these questions come to them with the shattering force of explosives, for engineering students are often conservative and a bit stolid intellectually. They should be made to argue, even if it jars them; for they will take an interest in those matters in which they participate.

The content of the course is more or less immaterial, since all great literature, of whatever period or race, will accomplish the same results. I begin with Sir Thomas More and include material by Spenser, Marlowe, Shakespeare, Bacon, Milton, Hobbes, Dryden, Pope, Swift, Addison, Steele, Goldsmith, Burns, Burke, the romantic poets, Carlyle, Ruskin, Arnold, Huxley, Tennyson, Browning, and of course some minor writers. My emphasis is on three aspects of literature: historical as it effects the development of the great ideas which are our racial heritage in politics, science and the social scene; biographical in so far as it makes these ideas plain or helps to humanize the authors and bring them down to the plane of the student's thinking; and philosophical.

The problem of getting students to prepare for the class discussions has been fairly simple, because I have adopted a scheme which I find thoroughly satisfactory. Students are told that they may expect ten-minute quizzes on any day, covering the day's assignment, and that no excuse or absence will be accepted if they fail to turn in a paper. Instead a certain number of the quiz grades, the lowest grades, of course, will not be allowed to count in the final average. For instance, if twenty quizzes are given, the four with the lowest grades will be struck off, so that they will not affect the final average. I try to give assignments which can be mastered in less than two hours of study. Other details of the conduct of the course will suggest themselves to the alert teacher. But I should note that I tell students that the examination will not be hard and that I shall grade more leniently than as if it were a technical course, since the amount they learn or fail to learn in a course in literature will have very little tangible effect on their later careers as technical men. I prefer the course to be one they will recall with pleasure. Lest the reader think that this

is a bid for numbers, I hasten to add that the course at the University of North Carolina is required of all sophomores.

To sum up, then, literature has a real place in the curriculum of the engineer, and he should be given a course in it which he will like and which will interest him. It should offer values which he will appreciate. Interest can be aroused by a preliminary lecture which places literature in the scheme of education, and it can be maintained by making the student a participator in the class hour, by catching his interest for the human side of literature and by the appeal of great ideas. It should leave him with a pleasant taste in his mouth and a fund of words, phrases and ideas which will help him to look at life with a critical eye, to judge correctly, and to understand something of the human spirit.

## NECROLOGY

### DWIGHT PORTER

Dwight Porter was born in Hartford, Conn., in 1855, and died February 26, 1935. He was graduated from Yale University in 1880. For three years he was a special expert agent on water power for the Tenth United States Census. In 1883 he joined the staff of the Massachusetts Institute of Technology as instructor in mathematics; in 1885 he was instructor of civil engineering, assistant professor in 1887, associate professor in 1890, and professor of hydraulic engineering in 1896. From 1914 until his retirement in 1921, he served as professor of hydraulics and sanitary engineering.

Professor Porter was a member of the New England Waterworks Association, the American Society of Civil Engineering, the Boston Society of Civil Engineers, and a charter member of the Society for the Promotion of Engineering Education.

## COLLEGE NOTES

Studies in the types and intensities of noise, its physical and psychological effects, will be a part of a noise survey begun at the **Case School of Applied Science** by Professor John R. Martin, assistant professor of electrical communications and by students of the department of electrical engineering. Professor Martin will direct the noise survey for at least a year in and near Cleveland in order to determine the effects of noise and by very accurate determination of types and intensities, as well as location, to give the public concrete data upon which some beneficial results may be based.

Professor Martin has mounted his equipment on a truck and thus will be able to set it up at various important points throughout greater Cleveland. The equipment consists of: a microphone to convert the noise into electrical energy, an amplifier and an output meter to indicate the strength of the electrical energy, and thus show the intensity of the noise.

"Solvenized" gasoline, developed by Dr. C. F. Prutton, associate profesor of Chemical Engineering, is the center of attention in the oil business in and about Cleveland. The new lubricant has the property of dissolving carbon-forming gums. It is claimed that operating temperatures are considerably reduced, that carbon formation is prevented, and that there is more efficient lubrication as a result of lower engine temperatures.

**Lehigh University.**—Recognizing the broad field and the future need for engineers, the Department of Civil Engineering offered a sanitary engineering option in 1933. Upon further consideration and much consultation with the Department of Chemistry, a curriculum in sanitary engineering was next projected as a joint effort of the two departments. This curriculum became effective in September, 1934. The details of administration are delegated to the department of Civil Engineering. The degree conferred will be that of Bachelor of Science in Sanitary Engineering. The technical portion of the curriculum has been constructed from courses now given in the two departments and in addition to basic work in these two fields and engineering in general, it includes geology, economics, biology, bacteriology, sanitary engineering, and non-technical electives.

## The Curriculum in Sanitary Engineering

### *Freshman Year—Uniform for all Engineering Students*

### *Sophomore Year*

| FIRST SEMESTER | | SECOND SEMESTER | |
|---|---|---|---|
| *Course* | *Cr. Hrs.* | *Course* | *Cr. Hrs.* |
| Economics | 3 | Economics | 3 |
| Quantitative Analysis | 3 | Quantitative Analysis | 3 |
| Quantitative Analysis Conference | 1 | Quantitative Analysis Conference | 1 |
| Introduction to Geology | 2 | Engineering Geology | 3 |
| Geology Field Trips | 1 | Intermediate Calculus | 3 |
| Elementary Calculus | 3 | Electricity, Magnetism and Heat | 3 |
| Mechanics, Light and Sound | 3 | Military Science and Tactics | 2 |
| Military Science and Tactics | 2 | Engineering Conference | — |
| Engineering Conference | — | Moral and Religious Philosophy | — |
| Moral and Religious Philosophy | — | | 18 |
| | 18 | | |

### *Junior Year*

| FIRST SEMESTER | | SECOND SEMESTER | |
|---|---|---|---|
| *Course* | *Cr. Hrs.* | *Course* | *Cr. Hrs.* |
| Biology | 3 | Sanitary Bacteriology | 3 |
| Chemical Engineering | 3 | Organic Chemistry | 3 |
| Organic Chemistry | 4 | Stresses | 3 |
| Mechanics of Materials | 3 | Electrical Machinery | 2 |
| Hydraulic Laboratory | 1 | Dynamo Laboratory | 1 |
| Non-Technical Electives | 3 | Heat Engines | 3 |
| | 17 | Non-Technical Electives | 3 |
| | | | 18 |

### *Summer*

| *Course* | *Cr. Hrs.* |
|---|---|
| Mechanical Engineering Laboratory | 4 |
| or Advanced Military Camp | 3 |

### *Senior Year*

| FIRST SEMESTER | | SECOND SEMESTER | |
|---|---|---|---|
| *Course* | *Cr. Hrs.* | *Course* | *Cr. Hrs.* |
| Chemical Research Laboratory | 2 | Industrial Organic Analysis | 2 |
| Industrial Biochemistry | 2 | Industrial Analysis Conference | 2 |
| Industrial Biochemistry Laboratory | 1 | Industrial Biochemistry | 3 |
| Structures | 3 | Chemical Engineering Practice | 1 |
| Reinforced Concrete | 3 | Highway Engineering | 2 |
| Concrete Laboratory | 1 | Foundations | 2 |
| Sanitary Engineering | 3 | Advanced Sanitary Engineering | 3 |
| Non-Technical Electives | 3 | Hydraulic and Water Power Engr. | 3 |
| | 18 | Hydraulic Engineering | 1 |
| | | | 19 |

**Massachusetts Institute of Technology.**—Edward L. Moreland senior partner in the engineering firm of Jackson & Moreland, will succeed Professor Dugald C. Jackson, who retires as head of the electrical engineering department next June.

Mr. Moreland brings to the department of electrical engineering a broad knowledge of engineering and a thorough understanding of educational requirements in a field in which he has had exceptionally wide experience. Although the future of the electrical engineering department now becomes Mr. Moreland's primary interest, nevertheless, he will continue his active affiliation as senior partner in the firm of Jackson & Moreland, thus maintaining a valuable relationship between technical education and the engineering profession.

The new head of Technology's electrical engineering department is a native of Virginia and a graduate of Johns Hopkins University and of Technology where he was awarded the degree of master of science in 1908. Mr. Moreland has been active in civic affairs and is chairman of the Wellesley Water and Municipal Light Commissioners and of the Sewer Commissioners.

Mr. Moreland was born at Lexington, Va., in 1885. He is the son of Sidney T. and Sally Preston Moreland, and his father was for many years professor of physics and dean of Washington and Lee University, later becoming professor of physics and dean of the premedical school of the University of Tennessee. Mr. Moreland received his early education at the McDonogh School of McDonogh, Md., where his father was principal for several years, and the Boys' Latin School of Baltimore. He received his bachelor of arts degree from Johns Hopkins University in 1905, coming directly to Technology for his advanced studies. Upon his graduation, he entered the Boston engineering firm of D. C. and Wm. B. Jackson, which in 1919 became the firm of Jackson & Moreland, from which Professor Jackson retired in 1930.

Professor Henry B. Phillips, who has been acting head of the department of mathematics since the retirement of Professor Frederick S. Woods, has been appointed permanent head of his department. Dr. Phillips has been a member of the staff since 1907, and is widely known as an author and teacher. He was graduated from Erskine College in 1900, and carried on advanced studies at Johns Hopkins University, where he was awarded his doctorate in 1905. He is the author of more than 20 books and papers on mathematics.

Again this year the student combined professional societies are responsible for the presentation of Open House. The faculty and administration are co-operating to make this an outstanding event of the school year. The twelfth Annual Technology Open House will take place on May 4th from 2 to 10 P.M. The Institute will be

in operation and open for inspection to show the interested public how a technical school operates. To make the scientific exhibitions interesting and understandable, student guides in uniform will be available.

The outstanding feature of Open House is that it gives a panorama of recent progress in science and engineering. Outstanding among the exhibits will be the following: Differential Analyser, Transmission of Sound on Light Waves, Magnetic Frying Pan, Machine for the Solution of Simultaneous Equations, Hardy's Color Measuring Analyser, and Grading of Wool for Maturity by Polarized Light.

**University of Michigan.**—A series of courses in advanced mechanics will be given during the summer of 1935. The courses are especially planned for teachers of engineering mechanics and graduates working for advanced degrees in this subject.

The courses include the following:

*Theory of Elasticity for Engineers,* Prof. R. V. Southwell, Oxford University, England.

*Theory of Vibrations with Applications in Engineering,* Prof. S. Timoshenko, University of Michigan.

*History of Mechanics,* Professor S. Timoshenko.

*Theory of Suspension Bridges,* Professor A. A. Jakkula (Civil Engineering Dept.).

*Theory of Thin Plates and Shells,* Professor E. L. Eriksen.

*Advanced Theory of Structures,* Professor L. C. Maugh (Civil Engineering Dept.).

*Aerodynamics,* Professor M. J. Thompson (Aeronautical Dept.).

Courses with which laboratory work will be given are as follows:

*Modern Developments in Fatigue Testing of Materials,* Dr. F. L. Everett.

*Photo-Elastic Methods of Stress Analysis.* Dr. E. E. Weibel.

A Seminar in Engineering Mechanics will accompany the courses, directed by Professors Southwell and Timoshenko. Several prominent professors and engineers have promised to participate. Professor Southwell is a Visiting Professor sponsored by Chrysler Corporation.

Communications for further information may be addressed to Professor Louis M. Eich, Secretary of the Summer Session, or to the Engineering Mechanics Department.

**Northeastern University.**—Dean Carl S. Ell has announced the appointment of three new members to the Day Division faculty to take effect in September, 1935. Dr. Waldo Cutler Peebles has been appointed Professor of Modern Languages, Dr. Howard Davis

Spoerl Instructor in Psychology, and Mr. Rudolph M. Morris Instructor in Education.

The following promotions of members of the Day Division faculty have also been announced, effective next fall: Dr. Carl F. Muckenhoupt to Professor of Physics and Head of the Department of Physics succeeding Professor Joseph A. Coolidge who has been Head of that Department in the School of Engineering for the past twenty-four years. Professor Coolidge will continue on the faculty but give his entire time to teaching and relinquish his administrative responsibilities to Dr. Muckenhoupt. Dr. Wilfred S. Lake has been promoted to Professor of Economics, Edward S. Parsons to Professor of Physical Education, Charles W. Havice of Professor of Sociology, Stanley G. Estes to Professor of Psychology, and William C. White to Associate Professor of Education.

The Department of Civil Engineering has this year developed several significant projects for engineering students employed under the Federal Emergency Relief Administration. A number of brass and wooden models of typical engineering structures have been planned and constructed under faculty supervision by Federal Aid Students. These projects have had a two-fold advantage: first to provide socially desirable and highly educative work for the students, and, secondly, to make available a number of very useful models for classroom demonstrations. Among the models already constructed in this way are the following: Floor Beam Connection to Girder—Through Girder Railway Bridge; Bottom Chord Joint Detail ($L_2$) of a 150′ Span Single Track Through Steel Railway Bridge of the Warren Type; Top Chord Joint Detail ($U_2$) of a 150′ Span Single Track Through Steel Railway Bridge of the Warren Type; Hip Joint Detail ($U_1$) of 150′ Span Single Track Through Steel Railway Bridge of the Warren Type; An 80′ Span Complete Single Track Through Girder Bridge.

These models are useful in both theoretical and design courses in that they enable students to better visualize the inter-relation of various members in the completed structure. Each model was first planned fully on paper. Complete pencil drawings were made, comparable to the shop drawings provided in regular practice, fully detailed, dimensioned, and with appropriate mark numbers for fabrication and assembly purposes. Second, a bill of material for each model was prepared from the drawings and an order made out for the purchase of material. In some cases paper templates were made of the various members of each model to facilitate laying-out in their fabrication. In others where several typical members were to be formed or where particular care was required to

obtain accurate assembly and alignment of parts, special jigs were constructed.

The brass model of a single track plate girder bridge is composed of uniform thickness brass for all parts (0.040″) and connected together throughout with 1/16″ diameter copper rivets. In the making of this model the students made their own holding on dies and rivet sets for the driving of the 10,000 to 12,000 copper rivets. In this bridge some 200 to 300 special length rivets were required in the splices. The students conceived and made up a special rig for forming them from 1/16″ copper wire. There were many problems involved in the assembly of the various parts to form the members and then in the assembly of the members to form a completed detail which they were called upon to solve and which were of great educational value.

The wooden models were constructed of white pine, the members being made up individually as is common practice, and then connected together on the gusset plates, forming the joint details. Rubber-headed nails were used for rivets. The attempt was made wherever possible and economical to carry out the model construction in accordance with shop practice for structural steel.

All of the model work was under the supervision of Professor Emil A. Gramstorff, a member of the faculty in the Civil Engineering Department.

## BOOK REVIEWS

*Marketing Industrial Equipment.* BERNARD LESTER, Lecturer in Industrial Eng., University of Pittsburgh, and Assistant Sales Mgr. of the Industrial Department of the Westinghouse Electric & Mfg. Company. Published in 1935 by the McGraw Hill Book Company, Price $3.50.

In his preface the author describes well the purpose of the book as follows:

"The business depression through which this country has been passing has disclosed how well we can design and manufacture productive machinery and how well we can use this machinery to produce goods in quantity at a low cost. But we have not learned how to distribute this machinery in an economical manner. This problem is still unsolved, largely because the engineering mind, absorbed in the technical details of the machine itself, is frequently not adapted to solving problems of a commercial character. But surely the distribution of durable or capital goods deserves at least as much careful thought as has been bestowed upon the distribution of merchandised, or consumer, goods."

In the book, the author considers in detail the character and extent of the industrial market and the production machinery and equipment required by Industry. This is followed by a suggested method for analysis of the product and its distribution. Especially is stressed the need for commercial research in the broad field of marketing industrial equipment. Then come several chapters covering the formation and operation of the Sales Organization, including headquarters and field branches. Of special interest is Chapter X, which considers Customer Analysis, Specifications, and Proposals. This is a field for engineering effort that previously has been but little considered. The final chapters discuss, from a practical viewpoint, sales promotion and future tendencies in marketing.

The selling or marketing of producer goods is distinctly a part of the field of engineering. Up to the present time most books devoted to selling have had in mind the technique and methods needed in the selling of consumer goods, or in the insurance, real estate and allied fields where knowledge of the product is often of less value than the art of persuasion and general high pressure salesmanship.

A large number of our Engineering students are looking forward to positions in corporations that produce capital goods. More

and more these corporations must depend on men with an engineering training and background to market them. It appears, therefore, that a course in marketing based on Mr. Lester's book could well be introduced in every engineering school. Especially in the advanced industrial engineering curriculum this course should be a requirement.

Beginning in 1931, the author gave at the University of Pittsburgh, a two credit Graduate course for each of two semesters on Sales Engineering with special reference to capital goods. The present book brings together the most important material developed in that and subsequent allied courses. I recommend that engineering administrators and teachers who may wish to broaden the present college curricula in engineering should read the book carefully and consider the possibilities of one or more courses based on its contents.

Altogether, the book considers from a practical point of view an important and hitherto neglected field in engineering.

E. A. HOLBROOK

*Elements of Specification Writing.* 4th Edition, 1935. RICHARD SHELTON KIRBY, C.E., of Yale University. Published by John Wiley and Sons, Inc., 167 pages. Price $2.00.

For many years Kirby's text on Specification Writing has been known for its thorough treatment of this subject and has been widely adapted as a text and reference.

The subject matter has been revised and extended with the addition of much timely material, keeping pace with the ever-changing contracting world. The order of chapters has been changed in several instances, resulting in a more logical sequence. Obsolete references have been eliminated and more recent ones added. As in the third edition the following subjects are treated: definitions, documents, contracts, bond, advertisement, proposal, composition of specification, complete coverage of general and specific clauses and a section devoted to problems. In addition to these topics an entirely new chapter "Torts and Independent Contractor" has been added, which serves to emphasize the legal background of many of the general clauses.

As was the case in the preceding editions, the fourth edition will be read with confidence by the student and turned to by the young engineer for an authoritative reference.

A. DIEFENDORF

*Hydraulics.* ERNEST W. SCHODER AND FRANCIS M. DAWSON. Second Edition. McGraw-Hill Book Company. 429 pages. $3.50.

Many alterations and addtions were made in the second edition of this text, which have increased its size. In this revision the

authors have given clearer presentations and more examples and problems have been included. A chapter, based on the more general method of fluid flow using Reynolds number, has been added, although the authors have not brought it up to date in keeping with the more recent literature. The chapter and appendix on orifices, unfortunately, do not refer to the A. S. M. E. Fluid Meters Report and do not give any of their data.

EMORY N. KEMLER

*Elementary Mechanics,* Revised Edition. JOSEPH B. REYNOLDS, Ph.D., Professor of Mathematics and Theoretical Mechanics, Lehigh University. Printed by Prentice-Hall, Inc., New York, 1934. Contains 336 pages.

A textbook on Elementary Mechanics that does not use calculus in deriving formulas. Rather, as in finding the center of gravity of the surface and volume of a hemisphere, Professor Reynolds in his explanation obtains the desired expression by dividing the figure into regular geometrical shapes.

There is an abundance of good problems in the text, most articles containing at least fifteen well chosen problems. In addition to the problems included in each article there are supplementary exercises at the end of each chapter that are referred to the articles in that particular chapter by number. There are no answers to any problems other than the sample problems.

The text does not contain a chapter on Moment of Inertia. The chapter headings (eleven in number) follow in order. Introduction, Resolution and Composition of Forces, Equilibrium of Rigid Bodies, Center of Gravity, Friction, Work, Kinematics, Kinetics, Energy, Impact, Simple Harmonic Motion.

W. IRWIN SHORT

The annual reference handbook of the A. S. H. V. E. has just been published. The Guide has four definite divisions—(1) Technical Data Section, containing 41 Chapters; (2) Catalog Data Section, giving condensed engineering information on manufacturers' products; (3) The Indices; (4) A. S. H. V. E. Roll of Membership.

The book has been greatly enlarged and improved and a new department in the technical data section is a series of Problems in Practice which accompany each chapter. The Guide is compiled annually by the Society for engineers and others interested in heating, ventilating and air conditioning and it is planned as a practicable, usable and authoritative reference book.

*Cost Accounting (Principles and Methods).* CHARLES REITELL. International Textbook Company.

The principles encountered in elementary and advanced cost accounting are effectively presented and explained in this book. A problem book of some 120 pages, covering all phases of the subject, and following the general arrangement of the book is provided.

The text throughout is very clearly written, in fact so much so that one who possesses a reasonable knowledge of costs will be able to comprehend the principles set forth in their entirety.

Four chapters of the book are devoted to the control and costing of materials. Purchasing and storekeeping methods and policies are explained before an attempt is made to describe the inventory and costing problems that apply to materials used in manufacturing. Much of this information is taken for granted in other texts on the subject.

The material contained in Chapters 31, 32, 33, and 34, although not new to the field of accounting, is more capably presented than one would expect to find in most textbooks of a similar nature. In this portion of the book, the author explains standard costs; the necessary prerequisites to the installation of a standard-cost system; the administration of such a system; and, illustrates quite vividly the bookkeeping involved.

The examples and illustrations are well chosen throughout the text. Especially is this true of the chapter entitled "An Illustrative Process-Order Cost System" in which the process is fully described, hypothetical cost data being supplied and utilized ingeniously on forms designed for the purpose.

The chapter devoted to the use of cost data as the basis for various reports is very good. The author's recommendations, if followed, should result not only in better reports but a more effective use of statistics vital to management in general.

The concluding chapter, emphasizing the need for planning in all lines of endeavor, is timely, recognizing as it does recent trends in industry which are rapidly bringing about a substitution of science for the older empirical order of things.

H. H. ROTHROCK

*Mechanical Vibrations.* J. P. DEN HARTOG. McGraw-Hill Book Company, 1934. 390 pages. $5.00.

While this book is written for use as a text it meets the needs of the practicing engineer and is a valuable contribution to the engineering literature.

The author has written a readable as well as a practical book on this subject. The mathematical treatment has been kept as ele-

mentary as possible. A knowledge of elementary dynamics and calculus is necessary, but no familiarity with differential equations is presupposed. Whenever they are used their solution is discussed in great detail.

The general fields covered by the eight (8) chapters are:

1. Kinematics of Vibration,
2. The Single Degree of Freedom System,
3. Two Degrees of Freedom,
4. Many Degrees of Freedom,
5. Multicylinder Engines,
6. Rotating Machinery,
7. Self-Excited Vibration,
8. Systems with Variable or Non-linear Characteristics.